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CANADA
DEPARTMENT OF MINES
Hon. Louis Coderre, Minister; A. P. Low, Deputy Minister

GEOLOGICAL SURVEY
R. W. Brock, Director.

MEMOIR 51

No. 43, Geological Series.

Geology of the Nanaimo Map-Area

BY

Charles H. Clapp

OTTAWA
GOVERNMENT PRINTING BUREAU
1914

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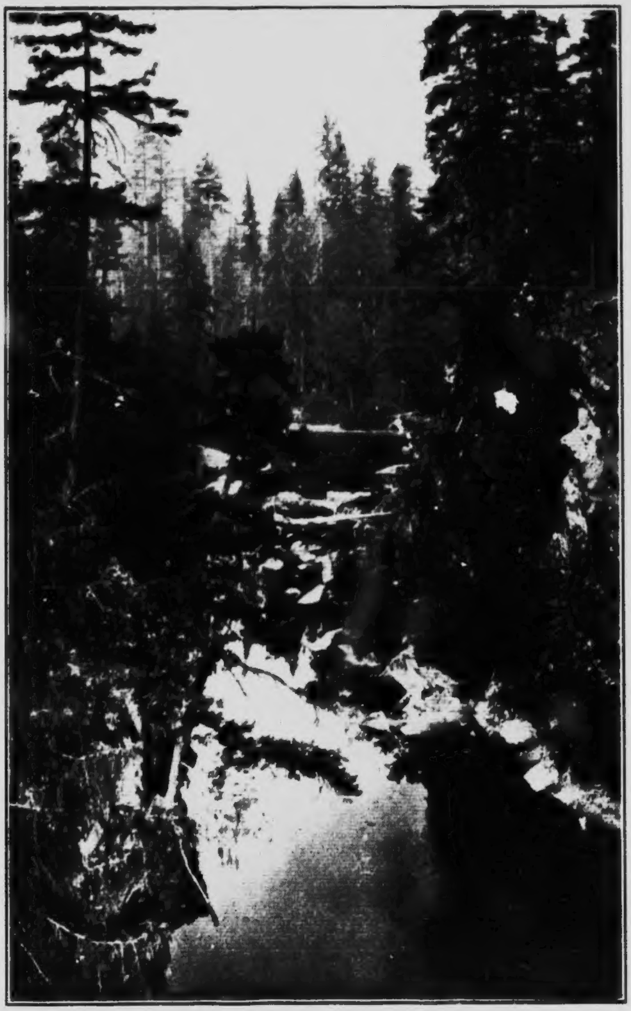

Nanaimo River canyon, looking west from the Esquimalt and Nanaimo Railway bridge; showing gorge cut in Protection sandstones by recently revived river.

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GEOLOGY OF THE NANAIMO MAP-AREA.

CHAPTER I.

INTRODUCTION.

GENERAL STATEMENTS AND ACKNOWLEDGMENTS.

The Nanaimo map-area includes the larger part of the Nanaimo coal field and all of its producing coal mines. The Nanaimo coal field is the most important of the Coast region. It has been the seat of a flourishing industry for 60 years, and has a very promising future, with a probable coal reserve of over a billion tons. At present, it produces over a million tons a year, more than one-third of the entire production of British Columbia. The elucidation of the geology should be helpful to all interested in the area, in particular to those prospecting for the extension of the known coal seams. This report presents, in a fairly detailed manner, the information gathered in the field and is accompanied by maps indicating the distribution and extent of the various rock formations, the position of the outcrops of the coal seams, the probable extent of the coal seams and their relation to the rock formations, the geological structure of the region, and the depths of the coal horizons.

In the work, the writer received, with one exception, the co-operation of all the coal companies operating in the district. Those who gave assistance are the Canadian Collieries (Dunsmuir) Company, Pacific Coast Coal Mines, and Vancouver-Nanaimo Coal Mining Company. Special acknowledgment is due to

Mr. W. J. Sutton, geologist for the Canadian Collieries Company, who very kindly gave the writer much information and assistance and accompanied him in the field on several occasions.

FIELD WORK.

The report is based on the detailed geological examination carried on during the summer of 1911. The Nanaimo topographical map, prepared in 1910 under the direction of R. H. Chapman, was used as a field map. This map is a fifteen-minute sheet, prepared on a scale of 1: 48,000 (1 inch = 4000 feet), but for use in the field enlarged photographically to a scale of 2 inches = 1 mile. Both the topographical and geological maps are published on the reduced scale of 1:62,500 (about 1 inch = 1 mile). In the field, a fairly accurate outcrop and drift map was prepared, virtually every outcrop being examined. From this, a bed-rock map, a map of the superficial deposits, and an economic geology map have been prepared for publication. The surface geological mapping was completed in less than three months. In this work the writer was very ably assisted by Mr. John D. MacKenzie. Another month was spent underground and in getting data from the mining companies.

LOCATION AND AREA.

The Nanaimo map-area, as may be seen on the accompanying index map (Figure 1), is situated on the east coast of Vancouver island, almost directly west of the city of Vancouver. It consists of a fifteen-minute rectangle, between longitudes 123° 45′ and 124°, and latitudes 49° and 49° 15′. The total land area is about 175 square miles and includes the city of Nanaimo and adjacent region, the larger (western) part of Gabriola island, and several smaller islands off the east coast of Vancouver island. As already mentioned, it also includes the larger part of the Nanaimo coal field. The following political districts of Vancouver island are included: Nanaimo, Cranberry, and Cedar, parts of Wellington, Mountain, Douglas, Bright, and Oyster. Nanaimo, with a population of 8,306 in 1911, is the only city in the map-area, although the southern boundary, the 49th parallel, passes through the northern part of Ladysmith. Small settlements occur near the larger mines, at Northfield, Chase River, South Wellington, and Extension.

There are many wagon roads and several railways in the area. The Esquimalt and Nanaimo railway traverses the area from north to south, and there are several coal mine and lumber railways. Thus, with the large amount of cleared lands, most of the area is readily accessible, the extreme southwestern portion being the only part reached and traversed with some difficulty.

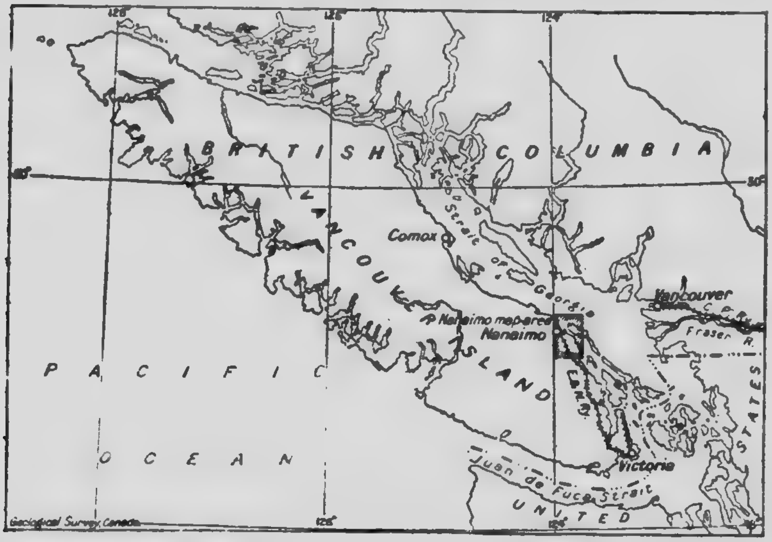

Fig. 1. Index showing location of Nanaimo map-area.

HISTORY.

A report on the geology of Nanaimo, whose development has been so intimately connected with coal mining on Vancouver island, would be incomplete without a brief summary of the history of coal mining on the island. The earlier history has been correctly and admirably summarized by Dr. G. M. Dawson[1] as follows:—

---

[1] Mineral wealth of British Columbia: Ann. Rept., Vol. III, 1887-88, p. 80R, 1889.

"The discovery of coal in British Columbia antedated that of gold by more than twenty years, but did not at first produce any effect comparable with that of gold upon the history of the country. Dr. W. F. Tolmie was the first to make known the existence of coal, on the coast of the province, in 1835. He was then stationed at the Hudson's Bay Company's post, known as Fort McLaughlin, on Millbank Sound. and specimens of coal were brought to him by Indians from the northeast coast of Vancouver Island, doubtless from Suquash. The steamer 'Beaver', belonging to the Company, arrived on the west coast in 1836, and thereafter small quantities of coal were obtained for her, as well as for blacksmiths' use, from this place, being derived from natural outcrops on the beach. In the year 1849, a coal miner was brought out by the Company, from Scotland, to more fully test the character of the coal on this part of the coast, and in 1851 a further number of miners and some necessary machinery were imported. Exploratory work by sinking and boring was prosecuted along the coast of Vancouver Island, between Port McNeill and Beaver Harbour, till 1853, but without resulting in any notable discoveries.

"Meanwhile in 1850, the existence of coal at Nanaimo had been ascertained by Mr. J.W.McKay, and in the following year it appears that most of the miners above referred to, were transferred from the northern end of the island to that place. Work began in earnest at Nanaimo in 1852, and before the close of 1853, 2,000 tons are reported to have been shipped, chiefly to San Francisco. The price of coal at Nanaimo was at this time $11.00 and at San Francisco $28.00 per ton. The Hudson's Bay Company, under the name of the Nanaimo Coal Company, continued to work the mines thus opened until 1861, when these were sold to the Vancouver Coal Mining and Land Company."

Most of the mining by the Hudson's Bay Company was probably carried on from the old shaft, now situated in the city of Nanaimo, west of Nicol street, although mining was done also on Newcastle island, and on the shore of Commercial inlet (probably near the causeway on Commercial street), where coal, the upper (Douglas) seam, was first discovered. Under the Vancouver Coal and Land Company, which was reorganized in 1889 and called the New Vancouver Coal Company, most of the large collieries in the immediate vicinity of Nanaimo were opened up. In 1902 the properties of the company were taken over by the Western Fuel Company, under whose management the collieries have been operated to the present time. The Western Fuel Company opened up the new Northfield colliery, or as it is better known, the Brechin mine, in 1905; and have recently completed two new shafts, 1,064 feet in depth, called the Reserve mine, and a slope, the Douglas mine, which was abandoned, it is said temporarily, during 1912.

In 1869 or 1870, Mr. Robert Dunsmuir discovered coal about 5 miles to the northwest of Nanaimo, at Wellington, although it is reported that he first located the Harewood mine, which was, however, sold to the Vancouver Coal and Land Company and was first worked by them during 1864 and 1865. The Wellington Collieries Company, of which Mr. Dunsmuir was the first president and chief owner, was organized and began to produce coal from the Wellington mines in 1871, the coal being shipped for long distance transportation, to Departure bay. The Wellington colliery was a large producer for several years but finally shut down in 1900. Meanwhile the same company had developed the Union collieries in the Comox district in 1888, the Alexandria colliery at South Wellington in the Nanaimo coal field in 1895, and the Extension collieries in the same field in 1899. The Alexandria colliery was shut down in 1902, but the other two collieries have been important producers to the present time. In 1910, all of the property of the Wellington Collieries Company was taken over by the Canadian Collieries (Dunsmuir) Company.

Several other collieries in the Nanaimo field have produced coal for short periods. Two of these smaller collieries are in operation at present, the South Wellington or Fiddick colliery of the Pacific Coast Coal Mines, and the New East Wellington colliery of the Vancouver-Nanaimo Coal Mining Company, both opened in 1907. The Pacific Coast Coal Mines, which was taken over during the present year, 1913, by the Pacific Coast Collieries, also operate a small colliery at Suquash, and have recently completed two new shafts in the Nanaimo field east of South Wellington, at Morden.

Since the beginning of coal mining in the Nanaimo district, the industry has shown a continuous, although fluctuating growth, and for the last three years has been producing over a million tons a year. The highest production was for 1911, when it reached 1,184,719 long tons.[1] The total production of the Nanaimo field to the end of 1912, is nearly 25,000,000 tons.

PREVIOUS WORK.

Although the Nanaimo district had been previously visited by geologists, who collected fossils, the first geological examination of importance was made in 1860 by Sir James Hector of the Government Exploring Expedition under the command of Capt. J. Palliser. Later, Dr. Robert Brown, who made several explorations from 1863 to 1866 on Vancouver island on behalf of the local government, made a short examination of the district. The first extensive examination was made by James Richardson of the Geological Survey, who worked for five years on the coal-fields of the east coast of Vancouver island, his results being published in the Reports of Progress for the years 1871-72, 1872-73, and 1876-77. His last report summarizes his work, and is accompanied by a map on a scale of 4 miles to 1 inch. Much prospecting has been done and many private examinations have been made since Richardson's reports were published; but of the extensive information thus collected very little has been made public, although the general progress of mining and prospecting has been recorded in the reports of the Minister of Mines of British Columbia for 1874 to 1912. In 1905, H. S. Poole collected some of the data, which appeared in the Summary Report of the Geological Survey for 1905. During the writer's work on Vancouver island previous to 1911, little attention was given to the Nanaimo coal field, and in his reports very little was published concerning it. A large part of the data collected in the district is in the hands of Mr. W. J. Sutton, geologist of the Canadian Collieries (Dunsmuir) Company, and he very kindly co-operated with the writer during the field season of 1911.

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[1] Compiled from returns in Rept. Min. of Mines, of British Columbia, &c.

The palaeontology of the coal measures, the Nanaimo series, was first specifically described by Meek, Shumard, and Gabb, all United States geologists, but has been most fully described, as well as summarized, by the late Dr. Whiteaves of the Geological Survey of Canada, in Parts II and V of Mesozoic Fossils, Vol. I, only one paper by him appearing since the publication of Part V in 1903. In Part II, Whiteaves described the fossils collected by Richardson from 1871 to 1875, and in Part V, he described fossils collected by Rev. G. W. Taylor, Mr. Walter Harvey, and Dr. C. F. Newcombe, all residents of Vancouver island, as well as those collected by Hector during the Palliser expedition, and those from the Provincial Museum at Victoria.

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CHAPTER II.

SUMMARY AND CONCLUSION.

GENERAL GEOLOGY.

The Nanaimo map area is a part of the east coast lowland of Vancouver island. This lowland has been developed by the more rapid erosion of sedimentary rocks of Upper Cretaceous age, the Nanaimo series, which fringe the east coast of Vancouver island, and rest unconformably upon the resistant metamorphic and granitic rocks composing the Vancouver range or upland which constitutes the larger part of Vancouver island. In the Nanaimo map-area the metamorphic and granitic crystalline rocks form three low ridges extending eastward from the upland to the west. The metamorphic rocks consist of metamorphosed andesites or basalts, of both flow and fragmental types, the flow types predominating, and metamorphosed fine grained sediments, originally carbonaceous shales and argillaceous sandstones, but now cherty and slaty rocks. They are correlated with two of the members of the Vancouver group, which in southern Vancouver island includes lower Jurassic and probably Triassic rocks, the meta-volcanics with the Vancouver volcanics and the metamorphic sediments with the Sicker series. The Vancouver volcanics are the most abundant in the Nanaimo map-area comprising the two northern of the three crystalline rock ridges; while the Sicker series forms only a narrow belt about a mile long in the extreme southwest corner of the map-area. Both the Vancouver volcanics and the Sicker series were greatly deformed and intruded by granitic rocks, probably in late Jurassic time, concomitantly with the intrusion of the extremely large Coast Range batholith.

The granitic rocks within the Nanaimo map-area are virtually confined to the southern of the crystalline rock ridges and are of three types. The principal type is a granodiorite, which is correlated with the Saanich granodiorite of southern Vancouver island. The granodiorite has an older and marginal facies of gabbro-diorite, into which it is intrusive. The last type, intrusive only into the Sicker series, is a gabbro of sub-porphyritic texture and is correlated with the Sicker gabbro-diorite porphyrites.

The granitic rocks were exposed by erosion before the deposition of the Nanaimo series, which rests in places on them. However, the metamorphic and granitic rocks were not worn down to a lowland, for the surface upon which the Nanaimo series was deposited is one of considerable relief, possibly as much as 2,000 feet. Small irregularities in the surface may be directly observed, and many of the contacts of the Nanaimo series with the underlying rocks closely follow the contours of present elevations, which must have been elevations at the time of deposition also, unless far more irregular and complex folding than is elsewhere observed is supposed. In addition it is found that the sediments resting on the older rocks in some places correspond with rocks considerably above the base in others.

The Nanaimo series consists of conglomerates, sandstones, and shales, and some coal. In general the conglomerates are composed chiefly of detritus of quartz veins and quartzose rocks, the sandstones chiefly of granitic detritus, quartz and feldspar, and the shales chiefly of detritus derived from the altered volcanic rocks. Although the various sediments succeed one another at short intervals and few of the individual beds have any great lateral extent, yet the series may be subdivided on a lithological and stratigraphical basis into various members or formations, each with its more or less distinguishing characteristics. As is shown by its fauna, the Nanaimo series is partly of marine origin, probably estuarine, since it was deposited on a surface of considerable relief, and under varying conditions, shown by the rapid vertical and lateral gradation of the sediments. As the series also contains land plants and coal, most probably of fresh water accumulation, terrestrial conditions must have alternated with marine conditions. The upper formation of the Nanaimo series, however, contains few or no marine organisms, hence it is possible that the alternating conditions were finally entirely replaced by terrestrial conditions. The lithological character of the sediments, the sandstones being composed chiefly of angular to subangular fragments, and of a large percentage of easily decomposed minerals, such as feldspar, indicates a very rapid accumulation and deposition in relatively small basins. The sedimentation began in Upper Cretaceous time, at a stage corresponding with the Chico or the Pierre, and it seems as if the sediments were first deposited in a marine basin, the Pacific Coast downfold, depressed at least as early as the upper Jurassic folding, between Vancouver island and the mainland. During the deposition, the sedimentation transgressed inland, at first filling up the hollows in the pre-Upper Cretaceous erosion surface, and then possibly covering even the higher residual elevations. The average thickness of the Nanaimo series was at least 6,760 feet toward the close of its deposition, and to the southeast of the Nanaimo map-area was over 10,000 feet.

It appears that the Nanaimo series was subject to local movements before the rocks became indurated, as very sharp and abrupt rolls occur even in the massive beds without developing any extra jointing or shearing. Also in the upper shales are numerous sandstone dykes which are the result of the injection of soft sands, derived from the sandstone interbedded with shales, forced into joints in the shales by local movements when the sandstones were still unconsolidated.

The Nanaimo series was moderately deformed also, presumably in post-Eocene time, since Upper Eocene sediments and volcanics to the south were similarly deformed, although the series may have been uplifted without being folded at the close of the Cretaceous. The series was deformed into broad, open folds, complicated by small, closed folds and reversed faults, the latter largely restricted to the western portion of the basin underlain by the series. The axes of folding have a general northwest-southeast strike, and the prevailing dip is to the northeast. At the northern rim of the basin, in the vicinity of Departure bay, the general strike turns to the northeast and east, while the dip is to the southeast and south. Since the prevailing dip is to the northeast and since closed folds, to the southeast of the map-areas, have been overturned to the southwest, the forces causing the deformation must have acted from the northeast, probably having their origin below the Pacific Coast downfold.

Before the Glacial period the deformed sedimentary rocks were worn down to a lowland, which is steeply surmounted by the crystalline rock upland to the west. The lowland still retains considerable relief, longitudinal valleys having been cut in the soft rocks between hard rock, cuesta ridges, up to 700 feet high and 3 to 4 miles long. It also appears as if the eastern part of the lowland was depressed below sea-level.

During the Glacial period the map-area was twice overridden by glaciers, chiefly by the southeastward flowing, piedmont Strait of Georgia glacier, which occupied the depression between Vancouver island and the mainland, and also by local valley and piedmont glaciers. As a result, the greater part of the map-area is covered with superficial deposits of various kinds, consisting largely of glacial detritus. These deposits are subdivided according to their lithological character and origin into the Admiralty till, deposited during the first epoch of glaciation; the Puyallup interglacial deposits, stratified clays, sands, and gravels; the Vashon drift deposited during the second and lesser epoch of glaciation; and the Colwood sands and gravels, a delta deposited during the recession of the Vashon glaciers at the front of two retreating valley glaciers.

Following the retreat of the Vashon glaciers the region was uplifted about 400 feet to its present position. The transverse streams crossing the lowland revived by the uplift, have terraced the Glacial deposits and have cut narrow canyons in the hard rocks. Alluvium has been deposited in lakes and swamps which formed in the poorly drained hollows of the drift mantle and in dammed glaciated valleys, and at the mouths of some of the larger streams deltas have been built. Along the shore, the uplifted Glacial deposits have been retrograded to form steep wave-cut cliffs and small beaches and bars of coarse sand and gravel.

ECONOMIC GEOLOGY.

Of the mineral resources of the Nanaimo map-area the coal deposits are of much the greatest value, and have been the source of a flourishing industry for 60 years. The only other products derived from the mineral deposits are building stone, sand and gravel, and common brick. Other deposits which have been prospected are the impure limestone (calcarenites) at Departure bay, and the mineralized shear zones and veins in the crystalline rocks.

There are at present three productive coal seams in the Nanaimo district, the Wellington, the Newcastle, and the Douglas. The lowest seam, the Wellington, occurs about 700 feet above the base of the Nanaimo series. The Newcastle and Douglas seams, which are only 25 to 100 feet apart, the Newcastle being the lower, overlie the Wellington seam by about 800 to 1,000 feet. A fourth and small seam overlies the Wellington at a distance of 20 to 60 feet. It also has been mined in a small way. The Wellington seam has been mined at Wellington, Northfield, East Wellington, Harewood Plains, and Extension, and is at present mined by the Vancouver-Nanaimo Coal Mining Company at East Wellington and by the Canadian Collieries (Dunsmuir) Company near Extension. The Newcastle and Douglas seams are usually worked together and have been mined extensively in the vicinity of Nanaimo. The mines there are operated by the Western Fuel Company. There has also been a large production from the Douglas seam south of Nanaimo, notably at Chase River, Southfield, and South Wellington. In these localities the Newcastle seam, although readily located, is of doubtful value. There is only one mine producing at present in this district, namely the South Wellington colliery operated by the Pacific Coast Collieries. Very recently the Douglas seam has been reached by two new shaft mines, by the Reserve mine of the Western Fuel Company, on the Indian Reservation near the mouth of the Nanaimo river at 1,064 feet, and by the Morden mine of the Pacific Coast Collieries, between South Wellington and the Nanaimo river at 610 feet.

Coal was first produced from the Nanaimo coal field in 1852, and to December 31, 1912, the field has produced about 24,500,000 long tons, approximately three-fifths of the total production of British Columbia. The present output is more than a million tons a year, over one-third of the entire output of British Columbia. The field has a promising future and the probable coal reserve of the entire field has been approximately estimated at about 1,340,000,000 tons.

The coals of the various seams are, as a whole, much alike and furnish a coking bituminous coal of fair grade. The amount of fixed carbon in the best quality ranges from 45 to 60 per cent, and the ash from 5 to 10 per cent. The seams are remarkably persistent considering the great variability of the associated rocks, but vary greatly in quality and thickness. In quality the seams vary from where they are entirely composed of clear bright coal with about 5 per cent of ash to where they are entirely composed of a dirty slickensided coal, called "rash," with over 50 per cent of ash. The relatively undisturbed coal seams are dirty, the dirty coal alternating with clean coal, and in places the seams are composed entirely of dirty coal or carbonaceous shale. The thickness varies from nothing to over 30 feet, in places within a lateral distance of less than 100 feet. This variation is caused by irregularities in either the roof or floor, and occasionally in both. The Wellington seam, which averages 4 to 9 feet thick, rests on a firm sandstone floor, which is fairly regular; while the roof, which is composed chiefly of sandy shale, is deformed. On the other hand the roof of the Douglas seam, averaging 3 to 6 feet in thickness, is chiefly a sandy shale with sandstone and conglomerate layers, and is comparatively even; while the floor, which is a weak sandy shale, is deformed. The deformed roof and floor, which are slickensided and contorted, bend sharply and the roof of the Wellington seam is in places overturned. At the thin places or pinches in the seams, the coal is dirty and slickensided, while in the swelled out portions it is chiefly clean and unbroken, with no definite and persistent partings or cleavage. In some instances the coal is clean and unfractured against the deformed roof or floor, but it is usually slickensided and even contorted. The strike of the deformations corresponds with the strike of the measures as a whole, that is generally northwest-southeast, and the swells occur on the southwest side of sharp bends and the pinches or overlaps are to the northeast. There are also several small faults and folds or wrinkles that affect the entire seam.

The Newcastle seam is more regular than the Wellington or Douglas, but is thinner, ranging from 20 to 60 inches where mined, and contains more numerous and regular partings. It is also less extensive in area than the other two seams.

The conclusions drawn from the facts given above are:—

(1.) That the original coal seams were dirty and that some of the "wants" are due to the lack of deposition of carbonaceous matter free enough from silt to form coal of sufficient purity to mine.

(2.) That the variations in the coal seams were caused by forces acting from the northeast, beginning at a time when some of the sediments and the coal relatively free from silt were soft or fairly plastic, and lasting through the general period of deformation, during which much of the lateral adjustment necessitated by the folding took place by lateral movements and sliding along the coal seams.

(3.) That the relative strength of the roof and floor determined in general the relative amount of deformation in each.

(4.) That the clean coal was more plastic than the dirty coal or rash and was, therefore, squeezed away from the tight bends where there was an increase in vertical pressure, to the limbs of the bends where there was a corresponding decrease in vertical pressure.

(5.) That the later deformations caused the greater part of the slickensiding and contortion of the coal, as well as the slight faulting and wrinkling.

The stratified sands and gravels of the superficial deposits furnish an abundant supply of these materials; but although the sands and gravels could be quarried cheaply they are not favourably situated for cheap water transportation. Except in a very limited way these deposits have been quarried only near the various railways for filling and grading purposes on the railway.

The surface clays of the map-area are, as a rule, very sandy, although some are fairly plastic, and they have been utilized only to a small extent for common brick. The various shales of the Nanaimo series are also sources of shale-clay. Most of the shales are sandy and of low plasticity and none of them are very refractory. They are used at present for common brick; and local shale-clays associated with the coal seams have been mixed with surface clays for the manufacture of sewerpipe and similar wares.

Some of the sandstones of the Nanaimo series have been quarried for building stone, although there was no production in 1911 and but little during the last few years. Some of the sandstones are concretionary, others soft and friable. The sandstones are not regularly or greatly jointed and large blocks may be obtained. The sandstones are as a rule of good colour, easily worked, and although rather soft directly after quarrying, harden with seasoning, and furnish building stone of fair grade.

The impure limestones or calcarenites of the Haslam formation of the Nanaimo series, exposed on the north shore of Departure bay, have been opened up as a test quarry for the production of material to be burned for lime. However, the percentage of lime, 42·41 per cent, is too low for the rock to be used for lime, and since the impurities are quartz sand, feldspar, and chlorite, the rock is not suitable for the manufacture of cement.

The crystalline rocks of the map-area are greatly fractured and sheared, and many of the shear-zones are impregnated with pyrite and chalcopyrite. A few prospects have been located on these mineralized shear-zones, but they are too low grade to be of any commercial value. The granitic rocks of Mount Hayes are cut by aplite and quartz veins. Both kinds of veins are mineralized, the former very sparingly, but the latter contain chalcopyrite and bornite in attractive amounts. One of these veins on the Thistle claim has been very carefully prospected, but the vein is too small to be commercially productive.

CHAPTER III.

GENERAL CHARACTER OF THE DISTRICT.

TOPOGRAPHY.

GENERAL ACCOUNT.

REGIONAL.

The Nanaimo map-area occurs on the east coast of Vancouver island. Vancouver island is one of the border ranges of North America and is separated from the mainland by the submerged northern portion of the great marginal depression of North America, known as the Pacific Coast downfold.[1] This depression is flanked on either side by great mountain ranges, in British Columbia by the Coast range to the east and the ranges of Vancouver island and Queen Charlotte islands to the west. The Vancouver range, which virtually constitutes Vancouver island, trends N. 55° W. The entire island is 290 miles long and 50 to 80 miles wide, the total area being about 15,000 square miles. It is, as stated, separated from the Coast range of the mainland by the submerged northern end of the Pacific Coast downfold, which is occupied from south to north by Haro, Georgia, Johnstone, and Broughton straits, and Queen Charlotte sound. It is separated from the mainland to the south, that is from the Olympic mountains of Washington, by a smaller transverse downfold striking about N. 70° W., now occupied by the Strait of Juan de Fuca.

The Vancouver range is composed of a heterogeneous group of deformed rocks having a general northwest strike, that were apparently reduced to a subdued surface, which was uplifted forming the plateau-like upland of Vancouver island, and then greatly or maturely dissected. Looking across the upland one can still see in the wide, relatively smooth inter-stream areas, the outlines of the subdued surface. In the southern part of Vancouver island it seems as if this surface before uplift was nearly a plain with only a few rounded hills composed of especially resistant rocks remaining a few hundred feet above the general level. In the central part of the island, however, the surface appears to have been one of considerable relief with larger and higher residual hills and small ranges of mountains. The present elevation of the upland surface, the uplifted subdued erosion surface, is less than 1,500 feet near the southern coast but increases rapidly to the northwest, so that in the central part of the island the elevation of the surface is about 4,000 feet, while the old residuals are now, since uplift, 5,000 to 7,000 feet above sea-level, a few peaks being even higher. As stated, the upland was maturely dissected. This occurred during a pre-Glacial erosion cycle presumably through the agency of the rivers of the old erosion surface, revived by the uplift. These rivers consisted of large transverse streams with tributaries which followed belts of the less resistant rocks. Along the coasts of Vancouver island are relatively narrow areas underlain by sedimentary rocks, which are less resistant than the crystalline rocks forming the larger part of the island, and which were, therefore, during the pre-Glacial cycle, reduced to lowlands. It seems as if at some time following mature dissection in this same pre-Glacial cycle, the southeastern part of the island was depressed partly below sea-level, drowning the valleys, but leaving the hills and ridges above sea-level as islands and promontories, and thus forming the irregular drowned coast characteristic of that part of the island.

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[1] Willis, Bailey, Tacoma Folio, No. 54, U.S. Geol. Surv., 1889.

During the Glacial period, the island was apparently smothered by a thick ice-cap, which smoothed and rounded all the mountains under 4,000 and 5,000 feet high; while the pre-Glacial valley heads in the higher mountains were excavated by local glaciers so that these higher mountains now have characteristic serrated summits. Valley glaciers occupied and scoured out the larger valleys, converting some of them, chiefly the transverse valleys draining southwestward from the main range to the Pacific, into fiords, and deepening some of the interior valleys into large lake basins. The valley glaciers flowing eastward from the east slope of the Vancouver range joined with the larger and more numerous glaciers flowing westward from the ranges of the mainland, and formed extensive piedmont glaciers which occupied the downfold between the Vancouver range and the ranges of the mainland. These piedmont glaciers overrode the east coast lowland of Vancouver island, removed virtually all surface soil, and smoothed off the angularities produced by normal erosion. On the retreat of the glaciers the lowland was left covered by a more or less persistent mantle of soft, superficial deposits. A recent uplift of some 250 to 400 feet has revived the streams crossing the lowland, and the revived streams have terraced the superficial deposits. Along the shore the uplifted superficial deposits have been retrograded to form steep cliffs, while the coast, where composed of the hard rocks, presents the initial irregularities of the drowned surface.

LOCAL

The Nanaimo map-area (see Figure 2) is a part of the southern portion of the east coast lowland of Vancouver island. The lowland has considerable relief; and since the sedimentary rocks underlying the lowland are of varying resistance, as well as moderately disturbed, their predominating strike being northwest and their dip northeast, extensive northwest-southeast valleys have been developed in belts of soft rock, between ridges

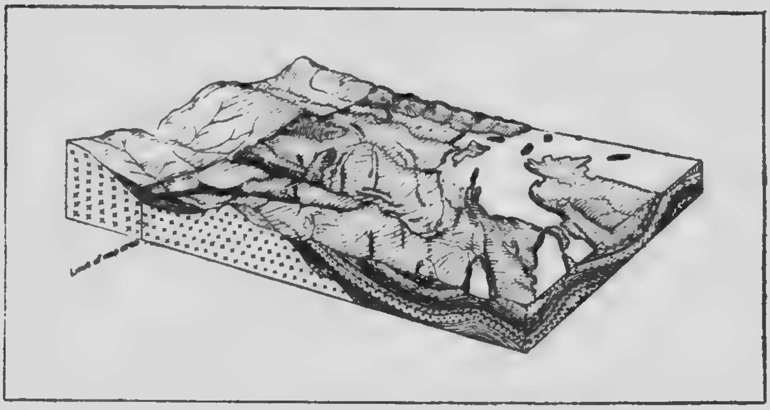

Fig. 2. Block diagram, illustrating character of topography of the Nanaimo map-area, looking northwest.

composed of more resistant beds. The valleys were probably reduced nearly to sea-level, but on account of the comparatively recent uplift have a present elevation of from 100 to 400 feet. The hard rock ridges are of the cuesta type with very steep, in places nearly vertical, front slopes at right angles to the bedding, and gentle back slopes nearly parallel to the bedding. The general elevation of the ridges increases from 300 to 700 feet in the eastern part of the area, to 500 to 1,000 feet in the western part. In the western or rather southwestern part of the area is the slope from the coast lowland to the crystalline rock upland to the west of the map-area, and tongues of the crystalline rocks extend eastward from the upland into the map-area, forming low, eastward trending ridges, increasing in elevation westward. Transverse valleys, formed by the larger streams flowing eastward from the upland, dissect the slope and the western portion of the lowland. The eastern part of the lowland was apparently depressed and the valleys drowned to form the long wide channels, passes, and harbours of the region, while the hard rock ridges remain above sea-level as points and islands, which are characteristically long and occur in chains. It was upon the lowland that the unconsolidated superficial deposits were laid down, the rocks of the lowland having been previously polished, in places smoothed to an even slope, and some of the valleys deepened, by the southeastward flowing piedmont and local valley glaciers. In some of the locally deepened valleys, in valleys dammed by the superficial deposits, and in irregular shallow depressions in the superficial deposits themselves, small lakes have collected, some of which have been filled or partially filled with alluvium. Since the recent uplift, which brought the land into its present position, the revived streams crossing the lowland have terraced the superficial deposits and have cut narrow canyons in the underlying indurated rocks (see Plate I); while along the shores the superficial deposits have been retrograded by wave attack to form cliffs 20 to 100 feet high, and small spits and bay bars have been built of the retrograded material.

DETAILED ACCOUNT.

LOWLAND.

The east coast lowland, as stated, comprises the larger part of the Nanaimo map-area. The lowland, which has, of course, a northwest-southeast trend parallel to the island, extends diagonally across the map-area, having a maximum width in the southern part of about 8 miles. The most characteristic features of the lowland are the longitudinal valleys cut in the soft rock and the hard rock, cuesta-like ridges. The largest of the longitudinal valleys extends through the central part of the lowland, the northern and southern ends being below sea-level, the submerged northern end forming a part of Nanaimo harbour and the submerged southern end forming Ladysmith (Oyster) harbour. Midway in its course the valley is entered from the west by the largest of the transverse streams flowing eastward from the upland, the Nanaimo river, which for the rest of its course flows northward in the valley, and is building at its mouth a fairly large delta which is rapidly filling the submerged northern end of the longitudinal valley (see Plate II). Smaller streams flowing southward in the valley are building a much smaller delta at the head of Ladysmith (Oyster) harbour. Another longitudinal valley, 2 to 3 miles to the southwest, called the Extension valley, follows an anticline, along the axis of which relatively unresistant rocks are exposed between limbs of resistant rocks which form cuestas 60 to 400 feet high fronting the valley. Another smaller but important valley, between the two described, has been developed in the soft rocks associated with the Douglas and Newcastle coal seams, and this valley is followed by the Esquimalt and Nanaimo railway for 3 miles.

Since the prevailing dip of the rocks is to the northeast, the northeast slope of most of the cuestas is the gentle, back or dip slope, while the southwest slope is the steep, front slope. In a few places, however, where the rocks are folded, chiefly near the inner border of the southern part of the lowland, fairly large cuestas, such as those developed to the southwest of the Extension valley, are formed by southwestward dipping rocks (see Plate IIIA). Similar but smaller cuestas occur near the outer

Nanaimo River delta, with east coast lowland in the middle ground and upland and Mt. Benson in the background.

A

B

A. Back slope of cuesta of southwestward dipping Extension conglomerate; southwest of Extension.

B. Front slope (fault-line scarp) of cuesta. Wellington seam outcrops half way up slope. Surface plant of No. 3 mine, Extension collieries.

border of the southern part of the lowland. In a few places the cuesta-ridges follow a folded, resistant stratum, the fold in all the cases noted being a southeastward pitching syncline. Thus crescent shaped ridges are formed, opening to the southeast, with gentle inner slopes and steep outer slopes. The best developed of the crescent-shaped cuestas is situated between the Extension valley and the larger valley to the northeast, and is half a mile south of Nanaimo river. It is half a mile across the crescent and three-fourths of a mile long, with a height of 20 to 100 feet. The northern part of a large cuesta 700 feet high, called the Woodley range, to the northeast of Ladysmith (Oyster) harbour, is a less perfect example of the same kind, the fold being of the nature of a broad synclinal warp. In a few instances, as to the southwest of Extension valley, cuestas have been developed where less resistant beds have been brought to the surface along old faults (see Plate IIIB). The general dip of the rocks of the lowland is low, usually from 5 to 20 degrees, so that the back slopes of the cuestas are very moderate, while the front slopes are frequently very steep, and as noted, are, in places, nearly vertical. With a few insignificant exceptions, the dip of the rocks is greater than 45 degrees only in the extreme southern part of the lowland near the inner border, and there the more resistant rocks form sharp crested ridges, resembling the hog-backs of the foot-hills of the Rocky mountains, with steep slopes on both sides. The size of the cuestas varies greatly, from small ledges a few feet in height and length to ridges 400 to 700 feet high and 3 to 7 miles long. As already noted, the general elevation of the ridges increases from 300 to 700 feet above sea-level in the eastern part of the lowland to 500 to 1,000 feet above sea-level in the western part.

Four transverse streams flowing eastward from the upland to the west, cross the western part of the lowland. These are, from north to south, the Millstone river, emptying into Nanaimo harbour, Chase river emptying into one of the channels of the Nanaimo river near the head of the Nanaimo River delta, Nanaimo river, and Haslam creek, which joins the Nanaimo river soon after it enters the large longitudinal valley in which the lower part of the Nanaimo river flows. The two northern streams are small and meander rather sluggishly across the drift covered lowland, cutting into the underlying rocks only in their lower courses. The two southern streams, the Nanaimo river being the larger, form large but rather narrow valleys, which not only dissect the lowland but also the slope to the upland. This slope, which curiously enough is underlain by one of the least resistant of the sedimentary formations, occurs in the southwestern part of the map-area, where it attains a width of nearly 4 miles. It is comparatively gentle, mounting from 500 to only 1,540 feet in this distance. It is largely drift covered and only the larger streams cut into the underlying rocks, but these streams, the rocks being relatively unresistant sandy shales, greatly fractured and also folded, have been able to incise or develop a meandering course. The slope is crossed at its widest part by Haslam creek.

Both the Nanaimo river and Haslam creek were revived by the recent uplift, and flow in narrow box canyons 100 to 300 feet deep incised in the bottom of their older and wider valleys (see Plate I). Where the Nanaimo river crosses belts of soft rock the inner gorge or canyon in which the river flows widens out, but where the river crosses into the hard rocks again the gorge invariably narrows to the typical box canyon, falls usually occuring in the river near the contact of the soft and hard rocks. In the walls of the canyon are numerous pot-holes, and at several places a section of the larger pot-holes is to be seen, where the side toward the river has been worn or broken away. The larger pot-holes, some of which are 80 feet deep, as that shown in Plate IV, invariably widen downwards, and some of those cut in the softer rocks are helical in shape. The development of these pot-holes and the subsequent destruction of their walls is doubtless one of the most effective of the processes of canyon formation. Although revived by the uplift responsible for the canyon cutting, the numerous tributary streams of Haslam creek, such as the North Fork, have not been able to incise themselves so rapidly as the main stream. Consequently at their mouths they fall abruptly or cascade into Haslam river, while their valleys hang above that of Haslam creek.

In most places the abrasion by the glaciers which overrode the lowland during the Glacial period amounted to little more

Plate IV.

Nanaimo River canyon, showing section of large pot-hole, enlarging downwards, 80 feet deep.

53141 – p. 24.

than a rounding and polishing of the rock surfaces. However, the longitudinal valleys, which correspond with the general S. 55° E. trend of the glacial movement, were deepened in places, and their sides, as may be seen to the northeast of Ladysmith (Oyster) harbour, were smoothed to even slopes. On the retreat of the glaciers much of the lowland was left mantled by superficial deposits. The earlier deposits appear to have been partially eroded by later glaciers leaving, west of Nanaimo, three or four uneroded portions as ridges half a mile long, an eighth to a fourth of a mile wide, and 60 to 100 feet high, with their long axes in the direction of glacial movement, about S. 50° E. Since the recent uplift the deposits, as noted, have been terraced by the revived transverse streams crossing them (see Plate XA).

In some of the eroded hollows of the drift mantle, small lakes have collected, Michael lake in the southeastern part of the map-area being an example. Numerous lakes occur also in the longitudinal valleys, which have perhaps been over deepened in places, but certainly have been partially filled and dammed by drift. No lakes occur entirely within the largest of the longitudinal valleys, although the northwestern portion of Quennel lake, the largest lake of the map-area, is situated in the eastern part of the middle portion of the valley. Quennel lake has an extreme length of about 4 miles and consists, as is shown on the topographical map, of several connecting arms, which follow soft rock valleys between small cuesta-ridges of harder rock. A similar but smaller lake, consisting of three connecting arms, occurs over a mile to the north and is called Holden lake, although it is also known, from its three arms, as Troisbras lake. Other smaller lakes occur in small longitudinal valleys in the eastern part of the lowland, Greenway lake southeast of Holden lake and Long and Priest lakes to the southeast of Quennel lake. Four small lakes occur in Extension valley, of the two northern, called the Overton lakes, the largest is less than three-fourths of a mile long, while the two southern, the Stark lakes, are only 700 and 800 feet long. Several other small lakes occur in longitudinal valleys, Cranberry lake, occurring in the valley which has been developed in the soft rocks associated with the Douglas and Newcastle coal seams, being the largest. No lakes occur on the slope to the upland, although there are a few small ponds

25 to 100 feet in diameter. At the northeastern base, however, are McKay and Crystal lakes.

In the southwestern part of the lowland to the west of the large longitudinal valley, is a terraced plain called the Nanaimo delta (see Plate XA), since it appears to be the result of the terracing after uplift, by the Nanaimo river and Haslam creek, of a delta built at their former mouths, before the recent uplift and during the recession of the youngest glaciers. The delta is 6 miles wide at its outer portion, but narrows at its head, along the Nanaimo river 3 miles from its outer portion, to a few hundred feet, and with this width it extends for another 3 miles up the river. Along the inner, western border of the broad portion of the delta, where there are many well developed kames and kettle or ice block holes (see Plate XB), the largest of which are 100 to 800 feet across and 10 to 80 feet deep, it attains an elevation of 400 feet above sea-level. From this it descends to the eastward nearly to sea-level, and even to sea-level in its southern portion, in a series of broad terraces varying in height from 10 to 50 feet. The lower portion of Haslam creek, which becomes overloaded in its course across the delta, splits into two meandering streams, while crossing the lowest terrace.

CRYSTALLINE ROCK RIDGES.

Three tongues of crystalline rocks extend eastward from the upland into the area of the Nanaimo map-sheet, and, as mentioned, form low, eastward trending ridges, increasing in elevation westward. One of these ridges having an elevation of 500 to 700 feet occurs in the extreme northern part of the map-area north of Departure bay, and since it extends to the shore, it forms a break in the east coast lowland and is the northern boundary of that portion underlain by the rocks of the Nanaimo basin. Another ridge in the central part of the map-area, attaining an elevation of 1,100 feet, is the east flank of Mt. Benson, a mountain about 3,300 feet high to the west of the city of Nanaimo. The third ridge occurs along the southern boundary of the map-area and is over 1,500 feet high in its western portion. A smaller tongue of crystalline rocks extending northwest from the eastern part of the ridge, forms in the central part of the southern portion of the map-area, a large rounded and isolated hill, 1,460 feet high, called Mt. Hayes, which is the most conspicuous elevation in the map-area. The ridges are drained chiefly by numerous, small, wet-weather, transverse streams. The rocks of the ridges have been rounded by glacial abrasion and on the north side of the northernmost ridge have even been worn into a fairly smooth slope. In one or two places, the small valleys have been more severely glaciated, and there is one lake on the northern ridge and two on the east flank of Mt. Benson, that appear to have collected in over-deepened rock basins. The two latter lakes have been increased in size by artificial dams and are used as reservoirs.

SHORE-LINES AND ISLANDS.

As described above, it was apparently the depression of the eastern part of the lowland with its longitudinal valleys in the soft rocks between cuesta-ridges of hard rocks, followed by a partial recovery, which resulted in the present irregular shoreline with its deep bays and long points and the numerous islands separated by long passes and channels. In the map-area there are two large channels, Northumberland channel in the east central part of the map-area, and to the south, along the eastern border of the map-area, Trincomali channel, which is the result of the drowning of a greatly denuded anticline.

The largest island of the map-area, Gabriola island, separated from Vancouver island by Northumberland channel, is situated in the northeastern part of the map-area, and extends 2 miles east of the map-area. The island is a synclinal ridge, 8 miles long and 2 to 3 miles wide, striking N. 60° W. Since the component rocks along the northeast and southwest coasts dip toward the centre of the island, these two coasts are steep, the southwestern being in places nearly vertical and having a maximum height of 500 feet. Between Northumberland channel and its southeastward extension, False Narrows, so called from its shallowness and many reefs, on one side, and Trincomali channel on the other, is the DeCourcy group of islands, formed by one of the more resistant formations of the northeastward dipping limb of the Trincomali anticline. The southwest limb of the anticline composes the ridges along the east coast of Vancouver island and one small island, called Round island, near the centre of the channel. Trincomali channel joins Northumberland channel by a narrow channel, between the De Courcy islands (Mudge island) and Vancouver island, half a mile long and only 200 to 400 feet wide, through which the tide rushes with great velocity. The other islands of the map-area are situated in the northern part, and of these, Newcastle and Protection islands are the largest. They are only a short distance from Vancouver island, and protect Departure bay and Nanaimo harbour, which are connected by Newcastle Island channel, from storms, which sometimes attain considerable strength in the open Strait of Georgia, between Vancouver island and the mainland. The other islands are all small, 1,000 to 1,500 feet in length, and with the exception of Five Finger island, 1½ miles from the crystalline rock ridge north of Departure bay and composed of the crystalline rocks, they are all of the cuesta type. They are interesting since they vary in trend, the rocks near the northern edge of the basin varying from their usual attitude. Brandon and Jesse islands in Departure bay trend east and west, their dip slope being to the south. Snake island in the north central part of the map-area trends north and south, its rocks dipping to the east, and Entrance island, in the northeastern part of the map-area, trends N. 60° E., its rocks dipping northwest. Of the long points characteristic of the east shore of Vancouver island, Jack point in the central part of the Nanaimo map-area is a conspicuous example.

The islands were overridden by the southeastward flowing piedmont glaciers and their ledges worn into rounded forms and the channels between them were presumably deepened. They were not left covered by a thick mantle of drift, and only at one place on Gabriola island has a lake, Hoggan lake, been formed in a rock valley, dammed by drift.

At two places along the shore of Vancouver island, at Departure bay and on the southwest shore of Kulleet bay in the extreme southeastern part of the map-area, the shore-line is in the drift deposit. In these two places the recently uplifted drift deposits have been retrograded during the present marine cycle to form cliffs 20 to 100 feet high. At Kulleet bay the retrograded material has built a bay bar across a small lagoon at the head of the bay. In a few other places also small beaches, bay bars, and tie bars have been built of the material of the drift cover, and as mentioned, at the mouth of Nanaimo river and at the head of Ladysmith (Oyster) harbour, deltas are being formed.

The greater part of the shore-line is in the hard rocks and presents virtually all of the initial irregularities of the depressed rock surface; although since the surface was, in general, regular, owing to the regular attitude of the sedimentary rocks in which it was cut, so the shore-line is fairly regular. Small coves and wave chasms have been cut in softer rocks and along joints and shear zones. Also in places where the coast is composed of thick-bedded sandstones with a calcareous cement, the cement has been partially dissolved by salt water spray and the wind and waves have fashioned the sandstones into hemispherical or hemicylindrical caves or "galleries" with fantastic, laceworked and honeycombed surfaces (See Plates VIII and IX).

CLIMATE AND VEGETATION.

The climate of Nanaimo and vicinity is remarkably uniform and temperate. The average temperature is about 40° F. in winter and 60 ° F. in summer, and the extremes of temperature are comparatively small. The rainfall is much less than in most other parts of the North Pacific coast, since the area is in the lea of the Vancouver range to the south and west, and of the Coast range of the mainland to the north. The average rainfall is about 35 inches a year, the greater part of the rain falling in the winter months, while the summer is dry.

The Nanaimo map-area was once heavily forested like other parts of the east coast of Vancouver island, the forest trees being chiefly conifers, Douglas fir and red cedar greatly predominating. But a great deal of timber has been cut, and in the wide valleys the land has been cleared and is now cultivated. Small fruit, garden truck, and grain are the chief agricultural products.

CHAPTER IV.

GENERAL GEOLOGY.

GENERAL STATEMENT.

REGIONAL.

Vancouver island is composed of deformed metamorphic volcanic and sedimentary rocks, intruded and replaced by numerous irregular bodies of granitic rocks, and is fringed along both coasts with fragmental sediments, which rest unconformably upon the older metamorphic and granitic rocks. Covering the hard rocks to a greater or less degree is a mantle of drift, which although partly stratified consists largely of glacial detritus. The metamorphic rocks are largely of lower Mesozoic age, presumably upper Triassic and lower Jurassic, but they probably include some Palæozoic members. Apparently the oldest rocks, considered provisionally as of late Palæozoic (Carboniferous) age, are a series of slates and quartzose schists and schistose, largely fragmental volcanics. These greatly metamorphosed rocks underlie a belt 2 to 7 miles wide, extending across the southern end of the island, and are called the Leech River formation and the Malahat volcanics.

The lower Mesozoic rocks compose the larger part of Vancouver island, and constitute the Vancouver group. They consist chiefly of metamorphosed basic volcanics called the Vancouver volcanics, principally meta-andesites. Associated with the Vancouver volcanics and occurring chiefly in small intercalated lentils is a formation of crystalline limestones called the Sutton formation. Besides this, there is associated with the meta-volcanics a series, the Sicker series, of stratified slaty and cherty rocks, composed partly of volcanic material. These rocks and their associated volcanics have been greatly metamorphosed and converted into schists.

All of the above-mentioned rocks have been intruded and partly replaced by batholithic and dyke (minor intrusive) rocks.

The batholithic rocks are chiefly granodiorite with marginal facies of diorite, and in the southeastern part of the island there are also gabbro-diorite and quartz diorite gneisses. All of the batholithic rocks are closely related and appear to have been irrupted during the same general period of intrusion. Nevertheless they may be subdivided into four types that were irrupted in a definite sequence, apparently as follows: Wark gabbro-diorite gneiss, Colquitz quartz diorite gneiss, Beale diorite, and Saanich granodiorite. It is probable that the "minor intrusives" also, acid and basic porphyrites, were irrupted during the same general period.

Unconformable upon an erosion surface of the metamorphic and granitic rocks, and confined for the greater part to the east coast of the island is a thick conformable series of fragmental sediments, the Nanaimo series, largely of Upper Cretaceous age, although the uppermost portion may be of lowermost Tertiary (Eocene) age. It consists of conglomerates, sandstones, and shales, with some coal. In general, it has been deformed into broad open folds with a northwest-southeast strike, and a general northeast dip, but in places it has been closely folded, overturned to the southwest, and broken by reversed and overthrust faults.

The deformation of the Nanaimo series probably occurred in post-Eocene time. Previous to it, during upper Eocene time, a thick formation of volcanic rocks, the Metchosin volcanics, which are chiefly basalts, was accumulated in the southern part of the island. These volcanics were involved in the post-Eocene deformation and at the same time were intruded by stocks composed chiefly of gabbro, called the Sooke intrusives.

Along the southwest coast of the southern part of the island, confined to small narrow basins, is a series of sediments of Miocene age, the Carmanah and Sooke formations. These sediments, largely coarse conglomerates and sandstones, were deposited under marine conditions and are remnants of a once more extensive Miocene coastal plain.

In Pleistocene time Vancouver island was covered by a thick ice cap, and large piedmont glaciers fed by valley glaciers from the ice caps of Vancouver island and the mainland filled the straits of Georgia and Juan de Fuca. The resulting glacial till remains on the upland, but in the larger valleys and on the coast lowlands the drift, although consisting largely of glacial detritus, is stratified, having been deposited by river, lake, and marine agencies. A second, but lesser period of glaciation followed the deposition of the stratified deposits, so that they have been partially eroded and covered with a younger glacial till. A recent uplift of some 250 to 400 feet has taken place, bringing the coastal lowlands, with their covering of stratified deposits, largely of marine origin, to their present position, some 200 to 600 feet above sea-level.

LOCAL.

The larger part of the Nanaimo map-area is underlain by the Nanaimo, Upper Cretaceous, sedimentary series. They rest unconformably upon the lower Jurassic and probably Triassic metamorphic rocks of the Vancouver group and the granitic rocks of the upper Jurassic granitic intrusives. The metamorphic and granitic rocks within the limits of the Nanaimo map-area, form three low ridges extending east from the upland west of the map-area. There are two members of the Vancouver group in the map-area, the Vancouver volcanics and the Sicker series. The Vancouver volcanics, which form the two northern of the low eastward trending ridges, are largely dense, green, altered andesites or basalts, greatly fractured and sheared, and cut by numerous quartz and quartz-epidote stringers, and in places impregnated and replaced by pyrite, especially in shear zones. The Sicker series are confined to the southern ridge and underlie only a narrow strip about a mile long. They consist of cherty and slaty rocks and are metamorphic, fine grained sediments. The Sicker series and Vancouver volcanics are greatly deformed and are intruded by the granitic rocks.

The granitic rocks are virtually confined to the southern of the three crystalline rock ridges. They consist of the Saanich granodiorite, with an older and marginal facies of gabbro-diorite into which the Saanich granodiorite is intrusive, and in the extreme southwestern part of the map-area, a gabbro porphyrite, called the Sicker gabbro porphyrite, which is intrusive into the Sicker series.

The granitic rocks were exposed by erosion before the deposition of the Nanaimo series in Upper Cretaceous time, but the surface upon which the Nanaimo series rests is one of considerable relief. Small irregularities are directly observable in exposed unconformities, and the contacts of the Nanaimo series with the underlying rocks, where not disturbed by intense folding and faulting, follow very closely the contours of present elevations, which must have been elevations at the time of deposition also, unless far more irregular and complex folding than is elsewhere observed is supposed.

The Nanaimo series consists of alternating conglomerates, sandstones, and shales, and contains the coal seams of the well known Nanaimo coal district. In general the conglomerates are composed chiefly of quartz and quartzose rocks, the sandstones chiefly of angular grains of quartz and feldspar with a greenish matrix of secondary ferro-magnesian minerals, and the shales chiefly of a carbonaceous, fine, siliceous mud and secondary ferro-magnesian minerals. A rather curious feature of the upper shale formations, especially of those characterized by a large number of thin sandstone interbeds, is the occurrence of numerous sandstone dykes, up to 3 or 4 feet wide. They cut the shales sharply, apparently along joint planes, and the shales are frequently bent or slightly contorted next to the dykes.

The various sediments of the Nanaimo series grade rather rapidly into each other in both vertical and lateral directions. Nevertheless the series may be subdivided on a lithological and stratigraphical basis into various members or formations (enumerated in the following table of formations), each with its more or less distinguishing characteristics. The total thickness of the Nanaimo series averages about 6,760 feet.

The Nanaimo series is moderately disturbed, and has as a whole, a general northwest-southeast strike and a prevailing dip to the northeast. At the northern rim of the Nanaimo basin the general strike turns to the northeast and east, while the dip is to the southeast and south. There are a few rather large open folds and many smaller and minor folds. Nearly all the folds have a northwest-southeast strike, and many of them, especially the minor folds, pitch, and flatten out to the southeast. The larger folds, proceeding from the southwest to the northeast, and occurring in successively higher formations (see accompanying maps) are—the Extension anticline, the Kulleet syncline, the Trincomali anticline, and the Gabriola syncline. Minor faults, seldom more than sharp rolls with a very small actual displacement, a few of which appear to have taken place while the sediments involved were still soft, are common. In the west central part of the basin are two large reversed or compression faults. These two faults, which occur to the southwest of the Extension anticline, have northwest-southeast strikes and steep dips to the southwest. The displacement of the faults, the southwestern side in each case being the upthrown, is about 500 and 150 feet. To the northeast of the Extension anticline are two problematical faults; these are both strike and presumably reversed faults, the northeastern side being the upthrown, with throws of 200 and 300 feet.

Before the Glacial period the deformed Nanaimo series were reduced to a lowland, which still retains, however, considerable relief, extensive valleys having been cut in the soft rock belts, while the hard rocks remain as ridges. During the Glacial period the lowland was twice overridden by glaciers and as a result a large part of the Nanaimo map-area is covered by superficial deposits of various kinds, which consist, however, largely of glacial detritus. They may be subdivided according to their lithological character and mode and time of deposition into the Admiralty till, deposited during the first epoch of glacial occupation; the Puyallup clays, sands, and gravels, deposited during the interglacial epoch; the Vashon drift, which mantles the earlier deposits, deposited during the second and lesser epoch of glacial occupation; the Colwood sands and gravels, a delta deposit formed during the retreat of the younger glaciers; and rock debris, and swamp, valley, delta, and beach alluvium formed or deposited during Recent time. Since Glacial time the Glacial deposits have been uplifted about 400 feet, and the stratified clays, sands, and gravels of the Puyallup and Colwood deposits, which are the most extensive, have been terraced by the streams revived by the uplift.

TABLE OF FORMATIONS.

Quaternary	Recent	Post-Glacial	Beach alluvium. Swamp, valley, and delta alluvium. Rock debris.
	Pleistocene	Later Glacial epoch.	
		Stage of glacial retreat	Colwood sands and gravels.
		Stage of glacial occupation	Vashon drift.
		Interglacial epoch	Puyallup clays, sands, and gravels.
		Earlier Glacial epoch	Admiralty till.
Tertiary	Eocene (?)		Dacite porphyrite dykes.
Mesozoic	Upper Cretaceous	Nanaimo [illegible]	
		Gabriola [illegible]	Chiefly sandstones.
		Northumbe[illegible]rmation	Conglomerates, sandstones, and shales.
		DeCourcy formation	Chiefly sandstones.
		Cedar District formation	Chiefly shale.
		Protection formation (Douglas coal seam.)	Grits, sandy shales; contains Douglas coal seam.
		Newcastle coal seam.	
		Cranberry formation	Shaly sandstones and sandy shale; some coarse sandstones and conglomerates.
		Extension formation	Chiefly conglomerates, some shales, sandstones, and small coal seams.
		Wellington coal seam.	
		East Wellington formation	Chiefly sandstone.
		Haslam formation (Marine shales)	Chiefly shale; some calcarinites.
		Benson formation	Basal conglomerates
	Upper Jurassic and, possibly, Lower Cretaceous	Granitic intrusives.	
		Sicker gabbro porphyrite (Position in column doubtful).	Masses and dykes.
		Saanich granodiorite	Batholith.
		Gabbro-diorite	Peripheral facies of Saanich granodiorite.
	Lower Jurassic and Triassic	Vancouver group.	
		Sicker series (Position in column doubtful).	Slaty and quartzose metamorphic sediments.
		Vancouver volcanics	Meta-andesites and meta-basalts.

DESCRIPTION OF FORMATIONS.

VANCOUVER GROUP.

The crystalline rocks upon which the sedimentary rocks of the Nanaimo series rest unconformably, consist of the metamorphic rocks of the Vancouver group and the granitic or batholithic rocks intrusive into them. There are two members of the Vancouver group in the Nanaimo map-area, the Vancouver volcanics and the Sicker series.

VANCOUVER VOLCANICS.

Distribution.

The Vancouver volcanics form two low ridges extending eastward from the crystalline rock upland west of the Nanaimo map-area. The northern ridge occurs in the northwestern part of the map-area, north of Departure bay, and is the northern boundary of the Nanaimo basin. The volcanic rocks extend below sea-level and outcrop in four or five places, a mile to a mile and a half off shore, forming West Rocks and Five Finger island. The southern ridge is the east flank of Mt. Benson, the mountain, 3,300 feet high, west of the city of Nanaimo. Another small outcrop occurs in the Nanaimo river, near the western boundary of the map-area. Although covered in places by a rather persistent mantle of glacial drift, the volcanic rocks are well exposed. Their contact with the overlying sedimentary rocks is exposed along the shore, and inland their boundary can be fairly well determined, except along the southeastern flank of the southern ridge.

Lithological Characters.

The Vancouver volcanics are uniform in appearance and typical of the meta-volcanics of the Vancouver group.[1] They are largely dense, rather fresh looking, dark green or greyish green meta-andesites or meta-basalts, frequently of porphyritic texture, with a predominating felsitic or aphanitic groundmass and phenocrysts of altered plagioclase feldspar, and altered hornblende or augite. They are fractured and sheared, cut by numerous quartz and quartz-epidote stringers, and in places impregnated and replaced by pyrite, especially in shear zones. Pillow structure may be observed at several places, and is especially well shown on West Rocks (see Plate V A). Fragmental varieties occur

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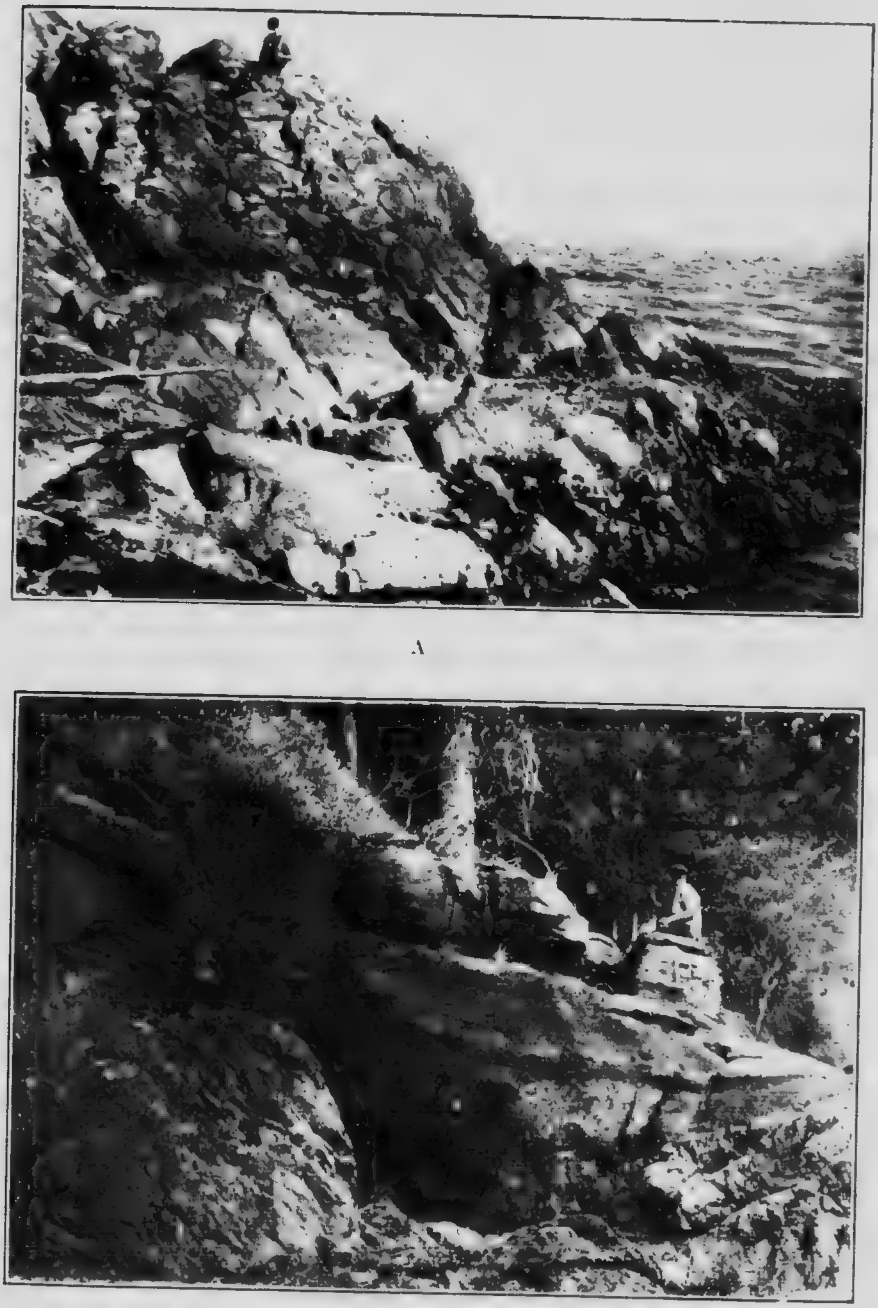
[1] See Memoir No. 13, Geol. Surv., Can., 1912, pp. 51-53

PLATE V.



A. Pillow structure in Vancouver volcanics; West Rocks.

B. Unconformity of the Nanaimo series and the underlying Vancouver volcanics; north shore of ridge north of Departure bay, 1½ miles west of Neck point; showing irregularities of the old unconformable surface.

but are not common. They are best exposed on the west shore of Hammond bay, near Neck point. They consist of fine tuffs, brownish red in colour, and agglomerates, with angular fragments up to 4 inches in diameter, of dense, red and green weathering meta-andesites or meta-basalts.

The groundmass is seen microscopically to consist essentially of small, lath-shaped crystals or microlites of andesine feldspar (ca. Ab. 55 An. 45), and hornblende or augite, the two last being largely altered to chlorite. The only important accessory mineral is magnetite, which occurs in fine grains and in small amounts. The granularity of the groundmass varies from glassy or microaphanitic to decimillimetre grained. The original texture of the groundmass is frequently obscured by alteration, but the feldspar laths usually have a diverse arrangement, with hornblende or augite in the interstices. The phenocrysts are of plagioclase, ranging from labradorite to andesine, and altered hornblende and augite. They are of small to medium size, 1 mm. or less to 3 mm. in diameter, and in some rocks are numerous, although the groundmass is always dominant. The degree of alteration is large, and besides chlorite, the secondary minerals, uralite, epidote, zoisite, calcite, sericite, kaolin, quartz, and pyrite and limonite are common. In some rocks hematite and magnetite are apparently secondary.

Structural Relations.

The Vancouver volcanics have been greatly deformed as is indicated by the fracturing and shearing they have undergone. Their attitude was not directly observed, but they probably have a general northwesterly trend with steep dips, in common with the rest of the Vancouver volcanics of southern Vancouver island. In other parts of Vancouver island the Vancouver volcanics are cut by the granitic rocks of supposed upper Jurassic age, and in the Nanaimo map-area the volcanics exposed in the bed of the Nanaimo river near the western boundary are cut by the Saanich granodiorite. Also certain amphibolite inclusions are found in the granitic rocks on the north slope of Mt. Hayes, and these may be greatly altered inclusions of the Vancouver volcanics. The Vancouver volcanics are unconformably overlain by the sedimentary rocks of the Nanaimo series, which rest in irregular hollows in the Vancouver volcanics (see Plate VB).

Mode of Origin, and Age and Correlation.

It has been concluded from evidence gathered in other parts of Vancouver island that the Vancouver volcanics were largely of marine origin.[1] Since pillow structure is supposed to be found only in submarine flows, its occurrence in the Vancouver volcanics supports this conclusion. In the Nanaimo map-area, no direct evidence as to the age of the volcanics is to be found except that they are pre-Nanaimo, that is pre-Upper Cretaceous. They are, however, so similar to the rest of the Vancouver volcanics of the island, that they are almost certainly correctly correlated with the rest. They are, therefore, placed in the Vancouver group, which in southern Vancouver island is known to contain lower Jurassic rocks and probably Triassic rocks.

SICKER SERIES.

Occurring only in the extreme southwestern corner of the Nanaimo map-area, and except for a few small outcrops, exposed only in the canyon of Haslam creek, are cherty and slaty rocks. Although more extensive southwest of the map-area, within it they underlie a strip about a mile long east and west, and 200 to 700 feet wide. The rocks are all fine grained sediments, originally thin bedded, carbonaceous shales and fine grained argillaceous sandstones, but now metamorphosed to cherty and slaty rocks. They are greatly deformed and even contorted, and have a general north-south to N. 25° W. strike, with steep dips, 50° to 80° to the west. They are cut by dykes of the Sicker gabbro porphyrite and to the south by a larger stock of the same. Although the contact is not exposed they are presumably cut by the Saanich granodiorite also. They are unconformably overlain by the basal conglomerate (Benson) of the Nanaimo series, which is steeply folded against the older rocks, and some faulting appears to have taken place along the contact. The rocks are identical with the metamorphosed sediments of the Sicker series of the Vancouver group,[1] considered to be of Jurassic or Triassic age, and are, therefore, correlated with and mapped as the Sicker series.

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[1] See Memoir No. 13, Geol. Surv., Canada, 1912, pp. 67-68.

GRANITIC INTRUSIVES.

The granitic rocks which are intrusive into the Vancouver group and unconformably underlie the Nanaimo series are of three types: gabbro-diorite, Saanich granodiorite, and Sicker gabbro or gabbro porphyrite. Except for their lithological characters, however, the types are described together.

DISTRIBUTION.

The batholithic rocks are almost entirely confined to a ridge which extends along the southern boundary of the map-area, and which forms the southern boundary of the Nanaimo basin. The Saanich granodiorite is the most abundant rock type, and a tongue of it extending northwest from the main mass to the south of the map-area, forms Mt. Hayes, which steeply surmounts the surrounding lowland, underlain by the Haslam shales of the Nanaimo series. The gabbro-diorite occurs along the north flank of Mt. Hayes. The Sicker gabbro or gabbro-porphyrite occurs in a large mass in the western part of the ridge, but only a very small portion is exposed within the Nanaimo map-area, in the southwestern corner. A very small boss of the Saanich granodiorite occurs also in the Nanaimo River valley near the western boundary of the map-area.

LITHOLOGICAL CHARACTERS.

Gabbro-Diorite.

The normal gabbro-diorite, which varies considerably in its lithological character, is a dark-coloured rock, chiefly of medium, but also varying grain, consisting of feldspar and hornblende, with disseminated pyrite. In places, the hornblende, apparently recrystallized, occurs in large rectangular crystals similar to those of the Wark gabbro-diorite gneiss.[1] Near its contacts with the intrusive Saanich granodiorite the gabbro-diorite is frequently very fine grained, and even passes into an amphibolite. These fine grained phases are commonly foliated and sheared. They are also altered, impregnated with pyrite, and cut by veinlets of quartz and feldspar; in places, the quartz and feldspar forming numerous bands parallel to the foliation.

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[1] Memoir No. 13, Geol. Surv., Canada, 1912, pp. 71-85.

The normal gabbro-diorite is seen microscopically to consist essentially of plagioclase feldspar ranging from labradorite (ca. Ab. 40 An. 60) to andesine (Ab. 75 An. 25) with a zonal growth, brownish green hornblende, and originally augite. The accessories are magnetite, pyrite, titanite, apatite, and in some varieties quartz. The texture is anhedral to subhedral, and crushed and partly recrystallized, or secondary hornblende poikilitically includes small feldspars. The alteration is moderate to large, and it is possible that much of the hornblende is secondary after augite. The other secondary minerals are green biotite, epidote, chlorite, calcite, sericite, and quartz. The finer grained and amphibolite phases are of similar mineral composition although they contain no traces of original augite, and are of anhedral texture. One fined grained phase, from the northeast slope of Mt. Hayes, near Bush creek, is very different in texture, consisting of diversely arranged laths of hornblende and some feldspar, with interstitial feldspars, and large irregular grains of titanite and smaller ones of magnetite.

Saanich Granodiorite.

The granodiorite is a rather uniform, light coloured, almost white weathering rock of medium grain and somewhat gneissic appearance, and occurs in large rounded ledges. It consists of feldspar, quartz, and hornblende and biotite, with accessory magnetite. The gneissic appearance, which is not pronounced, is due to the parallel alinement of the dark minerals, hornblende and biotite. The granodiorite also contains a few small, round, dark coloured segregations. Near the contacts of the granodiorite, hornblende and biotite are more abundant and the hornblende occurs in large rectangular crystals, which give the rock a somewhat porphyritic appearance.

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[1] Memoir No. 13. Geol. Surv., Canada, 1912, p. 97.

The normal rock is cut by lighter coloured aplite dykes and also by quartz-feldspar veins. The aplites are holocrystalline, but of fine grain, and consist almost entirely of quartz and feldspar. A few scattered grains of hornblende and biotite are the only dark minerals easily distinguished macroscopically. In some varieties, the quartz and feldspar are seen, on close inspection, to form a very fine graphic intergrowth, and since the feldspar is clear, these varieties have a uniform appearance. Dykes of them, therefore, resemble quartz veins, and have been prospected as such. The granodiorite is cut also by coarsely crystalline veins of quartz and white, opaque weathering feldspar, that contain metallic minerals, chiefly chalcopyrite and molybdenite.

The essential minerals of the normal granodiorite are andesine, (ca. Ab. 65 An. 35), microperthite and microcline, quartz, hornblende, and biotite, and the accessory minerals are magnetite, titanite, and apatite. The microperthite is a fairly coarse, irregular intergrowth, probably of orthoclase or microcline and albite, the former predominating. Andesine, which has a zonal growth in some varieties, is the chief feldspar, and forms about 35 per cent of the rock. Quartz forms about 25 per cent, microcline and microperthite about 15 to 20 per cent, and the dark minerals about 20 to 25 per cent. The texture is subhedral, some of the andesine and hornblende crystals being euhedral, but most of the crystals having irregular interlocking boundaries, some feldspar even being included in the hornblende. The gneissic appearance, noted macroscopically, is not readily detected microscopically, the quartz showing but little strain. In most places the alteration of the granodiorite is slight, the secondary minerals being biotite, chlorite, epidote, and sericite. Some varieties are, however, sheared, and more altered, and are traversed by sericitic veinlets. The rock although very similar to the typical Saanich granodiorite[1] is as a whole less altered and contains more microperthite and microcline, a more sodic plagioclase, and more biotite. These differences are, however, not sufficent to warrant the mapping of the granodiorite as of a different type from the Saanich granodiorite, although the writer is accustomed to think of the granodiorite of the Nanaimo map-area as the Ladysmith phase of the Saanich granodiorite.

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[1] See description Memoir No. 13, Geol. Surv., Canada, 1912, pp. 102, 103.

The aplites which cut the granodiorite are seen microscopically to consist essentially of orthoclase, microcline and albite, chiefly intergrown microperthitically, and quartz, with accessory biotite and hornblende, and titanite, magnetite, pyrite, and apatite, the accessory minerals being in very small amount, and not all of them present in any one rock. The quartz and feldspar are usually graphically intergrown, in places finely and in other places, coarsely. The alteration is very slight, sericite being about the only secondary [illegible]

Sicker [illegible]

The Sicker gabbro porphyrite is a dark green, medium to fine grained rock, consisting of feldspar laths in a groundmass of altered dark minerals, chiefly hornblende, with small but occasionally larger rectangular crystals or phenocrysts of feldspar.

It consists essentially of plagioclase feldspar, chiefly labradorite (ca. Ab. 40 An. 60), and a pale bluish green, uralitic hornblende, which is probably secondary after augite. Magnetite or ilmenite occurring in large skeleton crystals is virtually the only accessory. The texture is subporphyritic and subhedral, with diversely arranged feldspar laths and interstitial hornblende. The rock has been deformed, the deformation distorting the feldspars and fraying the hornblende. The alteration is slight to moderate, the secondary minerals consisting of shreds of biotite, chlorite streaks, and a little sericite. The rock is identical with some of the coarse grained gabbro phases of the Sicker gabbro-diorite porphyrite.[1]

STRUCTURAL RELATIONS.

Internal.

The gabbro-diorite is intruded and brecciated by the Saanich granodiorite, and the contact is usually marked by a complex of fine grained gabbro-diorite or amphibolite and granodiorite.

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[1] Memoir No. 13, Geol. Surv., Canada, 1912, pp. 78–80.

Both rocks are cut by granodiorite aplites and quartz-feldspar veins. The Saanich granodiorite and the gabbro-diorite are clearly related lithologically, and it is probable that the gabbro-diorite is a marginal or peripheral differentiate of the Saanich granodiorite. The relation of the Saanich granodiorite and the gabbro-diorite to the Sicker gabbro-porphyrite is not known.

External.

Elsewhere on Vancouver island the Saanich granodiorite is intrusive into all the rocks of the Vancouver group, and in the Nanaimo map-area, it is intrusive into the Vancouver volcanics exposed in the bed of the Nanaimo river near the western boundary of the map-area. The Sicker gabbro-porphyrite is clearly intrusive into the Sicker series exposed in Haslam creek, since it forms large dykes and masses in the Sicker series. Elsewhere on Vancouver island similar rocks form small to large masses, restricted in their occurrence to the Sicker series, into which they are always intrusive.[1]

All of the batholithic rocks are unconformably overlain by the sediments of the Nanaimo series, although the unconformable contact is not well exposed. However, the basal conglomerates or arkose sandstones of the Nanaimo series contain detritus derived from the batholithic rocks.

MODE OF ORIGIN AND AGE AND CORRELATION.

The granitic rocks have been crystallized from a molten state under deep-seated conditions. It is probable, however, that the Sicker gabbro porphyrite is an injected rather than a subjacent type. The Saanich granodiorite forms batholiths, and, as mentioned, the gabbro-diorite seems to be a marginal or peripheral phase of the Saanich granodiorite batholiths.

All the granitic rocks are intrusive into the lower Jurassic and Triassic rocks of the Vancouver group and are unconformably overlain by the Upper Cretaceous sediments of the Nanaimo series. They are all, therefore, of about the same age and were probably irrupted during the general period of batholithic intrusion of Vancouver island and the Coast Range of British Columbia during upper Jurassic and possibly Lower Cretaceous times. The granodiorite of the Nanaimo map-area is, as mentioned, similar to the Saanich granodiorite found elsewhere on Vancouver island, although it has some minor lithological differences. These, however, are not distinctive enough to prevent the correlation of the granodiorite with the Saanich granodiorite. The gabbro-diorite has the same structural relations as the Beale diorite[1] of Vancouver island, and similar, although not identical, lithological characters, being as a rule more "basic." The two types, however, can not at present be correlated sufficiently well to map the gabbro-diorite as being of the Beale type. As already mentioned, the gabbro-porphyrite of the Nanaimo map-area is undoubtedly a phase of the Sicker gabbro-diorite porphyrites.

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[1] Memoir No. 13, Geol. Surv. Canada, 1912, pp. 82–84.

NANAIMO SERIES.

General Description and Stratigraphy.

Lying unconformably upon the crystalline rocks are the thick series of sedimentary rocks of Upper Cretaceous age, which contain the coal seams of the Nanaimo district. The lower members of this series are fossiliferous, and have been designated by Dawson[2] as the Nanaimo series (group). The entire series of conformable sediments is, however, generally known as the Nanaimo series or Nanaimo formation. As the upper unfossiliferous member or formation (Gabriola sandstones) is very unlike the Eocene sandstones near the city of Vancouver, being much more indurated, it is very doubtful that it is of Eocene age as Dawson[3] suggests it might be. It seems best, therefore, to enlarge the scope of the name Nanaimo so as to embrace the entire conformable series of sedimentary rocks.

The Nanaimo series consists of conglomerates, sandstones, and shales, which are almost invariably sandy, and some coal. In the Nanaimo map-area the series has a total average thickness of 6,760 feet, and has a maximum thickness of 9,000 feet. In

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Memior No. 13, Geol. Surv., Canada, 1912, pp. 99–107.

[2] Dawson, G. M., "The Nanaimo group"; Am. Jour. Sci., Vol. 39, 1890, pp. 180–183.

[3] Dawson, G. M., Bull. Geol. Soc. Am., Vol. XII, 1901, p. 79.

other places on Vancouver island and on the small islands off the east coast the total thickness of the series is nearly 10,000 feet. As a rule, the various kinds of strata rapidly succeed one another, and in places the individual strata thin out rather abruptly or are replaced by strata of a different kind. In the Nanaimo map-area, however, many of the strata are fairly persistent and the series may be subdivided, but solely on a lithological and stratigraphical basis, since all the lower subdivisions contain an identical fauna, while the upper subdivision is unfossiliferous. Perhaps, strictly speaking, these subdivisions should be called "members"; but since most of the subdivisions, while more or less characteristic and well defined, consist of several kinds of strata and are of considerable thickness, the term "member" is not satisfactory as it at least connotes a single stratum or well defined group of strata of one kind. The subdivisions are, therefore, called formations, and each one is given a distinctive geographic name. The formations with their principal lithological character and thickness are enumerated in the following table. This is followed by a few type sections of the Nanaimo series, as measured on the surface and recorded in bore-holes, that illustrate the rapid vertical gradation of the sediments and the characteristic lithology of each of the formations.

TABLE OF FORMATIONS OF THE NANAIMO SERIES.

Name.	Lithological character.	Thickness.		
		Minimum	Maximum	Average.
Gabriola formation.	Chiefly thin to thick bedded, yellowish grey, fine to medium grained, and in places concretionary, sandstones, and some shaly sandstones and sandy shales, especially in the upper portion........	1,400	1,400	1,400
Northumberland formation.........	Grey sandy shales at top and bottom with sandstone interbeds and dykes, and a middle portion of thin to thick bedded, yellowish grey, fine to coarse grained, and concretionary sandstones, and coarse conglomerates, with predominating well-rounded fragments of granitic, porphyritic, and quartzose rocks	1,100	1,200	1,150

TABLE OF FORMATIONS OF THE NANAIMO SERIES—*Con.*

Name.	Lithological character.	THICKNESS.		
		Minimum	Maximum	Average.
DeCourcy formation	Chiefly thick bedded, greenish grey, fine to coarse grained, gritty and even pebbly sandstones, in places cross stratified and concretionary, and some thin bedded to shaly sandstones and sandy shales............	800	1,400	900
Cedar District formation...........	Chiefly grey, carbonaceous and ferruginous sandy shales, with numerous thin interbeds and dykes of brownish grey, fine grained sandstone, and some thicker interbeds of yellowish grey, coarser grained sandstones..........	700	1,000	750
Protection formation..............	Chiefly thick to thin-bedded greyish white, fine to medium grained sandstone, in places coarse grained and pebbly, and thin interbeds of shaly sandstone and sandy shale......................	600	750	650
Newcastle formation (Douglas coal seam)	In places composed chiefly of a greenish grit and in other places composed chiefly of dark green sandy shales and shaly sandstones with lenses of grit. Contains Douglas coal seam..................	125	400 ?	175
Newcastle coal seam				
Cranberry formation	Chiefly thin bedded to shaly, dark green, fine to coarse grained sandstones, in places pebbly, numerous interbeds of dark green sandy shales and in places in the middle and lower portions fine sandy conglomerates..............	200	600	400
Extension formation	Chiefly quartzose conglomerate and some coarse grained sandstones, with interbeds especially in lower portion, of sandy shales and small coal seams.................	500	1,000	600

TABLE OF FORMATIONS OF THE NANAIMO SERIES—*Con.*

Name.	Lithological character.	THICKNESS.		
		Minimum	Maximum	Average.
Wellington coal seam.				
East Wellington formation.........	Chiefly flaggy, olive grey, fine to medium grained sandstone, few thin interbeds of sandy shales and in places of conglomerates	25	50	35
Haslam formation..	Chiefly thin bedded, light to dark grey, sandy and frequently carbonaceous and in places concretionary shales and fine grained shaly sandstones. Toward the base predominating sandstones and arkoses,and near Departure bay, sandy calcarenites.	150	800	600
Benson formation...	Basal conglomerate. . . .	0	400	100
	Total....................	5,600	9,000	6,760

Section of the Nanaimo series exposed along the shores of Gabriola and Mudge islands, and on Vancouver island near Dodd narrows, including the Gabriola, Northumberland, DeCourcy, and part of the Cedar District formations.

Gabriola formation. Total thickness 1,379 ft.	Thickness in feet.
Medium to thin bedded and shaly, yellowish grey, medium grained, sandstone........	115
Bluish grey sandy shale........	2
Thin bedded, shaly sandstone and sandy shales........	17½
Thick bedded sandstone........	7
Bluish grey sandy shale........	22½
Medium bedded, yellowish grey, sandstone........	22
Bluish grey sandstone........	2
Concealed, probably shaly sandstone........	103
Medium bedded and in places concretionary sandstone, and some with platy structure........	205
Thick bedded sandstone........	26
Shaly sandstone........	½
Thick bedded sandstone, with platy structure........	22½
Thick bedded sandstone, with some shaly sandstone interbeds........	40
Yellowish grey, medium grained sandstone........	18
Yellowish grey, coarse grained sandstone........	4½
Calcareous shale........	1
Yellowish grey, medium grained and in places concretionary sandstone..	59
Thin bedded, shaly sandstone (partly concealed)........	39
Thick bedded sandstone........	17½
Sandstone, with shaly sandstone interbeds........	41½
Concealed........	12½
Sandstone........	16

Gabriola formation. Total thickness 1,379 ft.—*Con.*	Thickness in feet.
Concealed	4½
Thick bedded sandstone	41
Concealed	14
Thick bedded sandstone	52½
Thick bedded sandstone, with platy structure	31½
Concealed	34
Medium to thick bedded sandstone, with thin lentils of shale	85
Thick bedded, yellowish grey, medium grained sandstone, with shaly sandstone lentils	90½
Shaly sandstone	1
Thick bedded sandstone	7½
Concealed	9
Thick bedded, yellowish grey sandstone	22½
Concealed	33
Thick bedded concretionary sandstone	40½
Shaly sandstone	5
Sandstone	2
Sandy shale	½
Sandstone	2
Sandy shale	4
Sandstone	4
Sandy shale	½
Thick bedded sandstone	7
Shaly sandstone, with sandstone interbeds up to 18 inches thick	17½
Thick bedded, light grey, medium grained, concretionary sandstone	76
Northumberland formation. Total thickness ca. 1,134 ft.	
Dark bluish grey, concentric weathering sandy shales	63
Yellowish grey, medium grained sandstone	10
Bluish grey shale	30½
Grey shale with thin beds of sandstone	101½
Concealed, probably shale	35
Sandstone	20
Concealed	17
Thick bedded sandstone	39
Concealed	10
Coarse conglomerate, pebbles of granitic, porphyritic, and quartzose rocks	10
Concealed	8
Thick bedded sandstones (calculated thickness) ca	280
Grey sandy shale and thin beds of sandstone (calculated thickness) ca	510
DeCourcy formation. Total thickness ca. 933 ft.	
Thick to thin bedded sandstones and some shaly sandstones and sandy shales (calculated thickness) ca	200
Thick bedded greenish grey, yellowish weathering, coarse grained to gritty sandstone, with platy structure, and concretionary in places	190
Coarse grained, thin bedded, and shaly sandstone	8
Thick to medium bedded sandstone	31
Thick bedded, medium grained sandstone	44
Shaly sandstone	6
Thick bedded, coarse grained, and concretionary sandstone, with some shale lentils	145
Thin bedded, coarse grained sandstone, with shaly sandstone interbeds up to 10 inches thick	7½
Thick bedded sandstone, with shaly sandstone interbeds up to 18 inches thick	154
Bluish grey sandy shale	5
Sandstone	2
Shaly sandstone, with thin interbeds of coarse grained sandstone	24½
Coarse grained sandstone	4
Bluish grey shaly sandstone, with thin interbeds of coarse grained sandstone	6½
Bluish grey sandy shale	7½
Thick bedded sandstone	8½
Thick bedded sandstone, with interbeds of shaly sandstone	27
Shaly sandstone, with interbeds of coarse grained sandstone	38½
Thick bedded, coarse grained sandstone	24

Cedar District formation..	Thickness in feet.
Bluish grey, sandy shale, with thin sandstone interbeds	16
Sandstone	5
Bluish grey, sandy shale, with thin sandstone interbeds	17

Section of the Nanaimo series, exposed along the east shore of Protection and Newcastle islands, including the Protection, Newcastle, and upper portion of the Cranberry formation.

Protection formation. Exposed thickness 605 ft.	Thickness in feet.
Thin bedded, yellowish grey, medium grained sandstone..	44
Light grey, concretionary sandstone	6
Shaly sandstone	7
Concealed	9½
Thin bedded, greyish white sandstone	15
Thick bedded, greyish white sandstone	13½
Carbonaceous shaly sandstone	½
Thick bedded sandstone	4½
Shaly sandstone	½
Thick bedded sandstone	3
Shaly sandstone	½
Sandstone	½
Concealed	5
Thick bedded sandstone, with platy structure	15
Shaly sandstone	8½
Grey, concretionary sandstone	2
Greyish white, shaly sandstone	9
Thick bedded sandstone, with platy structure	7½
Carbonaceous shale, with coal lenses	1
Shaly sandstone	1
Thin bedded sandstone	3½
Thick bedded sandstone, with platy structure	9
Shaly sandstone	8
Concealed, probably shaly sandstone	4½
Shaly sandstone	10
Thin and medium bedded sandstone	107
Thin bedded sandstone, with bands of dark grey, carbonaceous shale	19
Thick bedded, greyish white, cross stratified sandstone	17
Thin bedded and shaly sandstone, greyish white, carbonaceous in places	17
Carbonaceous and coaly shale	½
Shaly sandstone	5
Thin bedded and shaly sandstone	8½
Concealed	7½
Thick bedded, greyish white sandstone	32
Concealed	7
Thick bedded sandstone	19
Shaly sandstone	1
Concealed	36
Thick bedded, greyish white sandstone	110
Thin bedded and shaly sandstone	3
Thick bedded, greyish white sandstone	27

Newcastle formation. Total thickness 176 ft.	
Grey, sandy shales, with thin sandstone interbeds	27
Concealed	25
Yellowish grey, medium grained sandstone	21
Concealed (Douglas coal seam)	68
Sandy shales, with sandstone interbeds, up to 2 feet thick	32
Newcastle seam	3

Cranberry formation.	
Concealed	48
Grey, shaly sandstone	4

Section of the Nanaimo series in the vicinity of Millstone river, including most of the Newcastle formation, the Cranberry formation, and the upper portion of the Extension formation.

	Thickness in feet.
Newcastle formation. Thickness in section 175 ft.	
Grey, buff weathering, fine sandy conglomerate, predominating sandy matrix, pebbles chiefly well rounded and quartzose	15½
Olive grey, fine grained, concentric weathering sandstone, thin bedded and rather shaly, with more massive interbeds up to 2 feet thick	47½
Concealed, probably sandy shales and Douglas coal seam	20
Fine, rather sandy or gritty conglomerates, with subangular to rounded chiefly quartzose pebbles	62½
Concealed, probably sandy shales and Newcastle coal seam	29½
Cranberry formation. Total thickness 234 ft.	
Thin bedded and shaly, dark greenish grey, concentric weathering sandstone	49
Concealed	11
Thin bedded to shaly, olive grey, medium grained, sandstone	5½
Fine conglomerate, with sandy matrix and subangular to subrounded pebbles, averaging ½ inch in diameter, of quartzose and meta-volcanic rocks	5
Concealed	6½
Thin bedded, olive grey, medium grained, concentric weathering sandstone.	10½
Concealed	11½
Thin bedded and shaly sandstone	5
Sandy conglomerate, with quartzose pebbles up to 3 inches in diameter, averaging ½ inch in diameter	19
Grey, medium grained sandstone	8
Concealed	9
Sandy conglomerate, with quartzose pebbles	22
Medium to thick bedded, yellowish grey, medium grained sandstone	25½
Concealed	24
Coarse to medium grained sandstone, grading into fine conglomerate at the base	22½
Extension formation. Total thickness ca. 557 ft.	
Fine sandy conglomerate growing coarser grained downwards	26
Coarse to medium grained conglomerate, with quartzose pebbles and sandy matrix, growing sandy toward the base	51
Concealed	18
Coarse to medium grained, conglomerate, with quartzose pebbles and sandy matrix	3
Concealed, probably conglomerate as above	27
Coarse to medium grained conglomerate, with quartzose pebbles and sandy matrix	132
Largely concealed to base, but includes sandstones, shales, and conglomerates ... ca.	300

Record of bore-hole through the lower portion of the Extension formation, the Wellington coal seam, and the East Wellington formation to the Haslam formation, Mountain district.

	Thickness in feet.	Depth in feet.
(Extension formation)		
Clay and coarse gravel	23	23
Grey sandstone	112	135
Dark shale	2	137
Sandy shale, carbonaceous in places	61	198
Brown shale	2	200
"Fireclay"	1	201
Coal	½	201½
"Fireclay"	12½	214

	Thick-ness in feet.	Depth in feet.
(Extension formation)—*Con.*		
Sandy shale, carbonaceous in places	22	236
Fine grained sandstone	24	260
Sandy shale	8	268
Fine grained sandstone	36½	304½
Dirty coal and shale	3½	308
Soft brown, carbonaceous shale	41	349
Coal (Little Wellington seam)	3	352
Soft brown, carbonaceous shale	36	388
"Fireclay"	10	398
Dark shale	13	411
Fine grained sandstone	6	417
Sandy shale	2	419
Dark shale	9½	428½
Coal (Wellington seam)	5½	434
(East Wellington formation)		
Fireclay	3	437
Sandy shale	1	438
Dark sandstone	3	441
Fine grained sandstone	33	474
(Haslam formation)		
Shale (contains marine shells)	47	521

Summary record of bore-hole through the lower portion of the Cedar District formation, the Protection formation, and upper portion of the Newcastle formation to the Douglas coal seam, Cedar district. (Dips steep in places so that the relative thickness of some beds is exaggerated).

		Thick-ness. in feet.	Depth in feet.
Superficial deposits		36	36
Clay and sand		......	......
Cedar District formation		378	414
Close grained, slate coloured, sandy shale	176 ft.	..	
Thin bedded sandstone, shaly sandstone, and sandy shale	179 ft.	......	......
Coal	2⅜ ft.	......	......
Shaly sandstone	20⅝ ft.	......	......
Protection formation		754	1168
Fine to coarse grained sandstone	76 ft.	......	......
Dark shaly sandstone, carbonaceous sandy shale, and sandstone	35 ft.	......	.. ..
Grey, fine grained, and in places shaly sandstone	39 ft.	......	......
Sandy shale, in places carbonaceous	6 ft.	......	......
Sandstone and shaly sandstone	89 ft.	......	......
Coarse grained grey sandstone	34 ft.	......	......
Shaly sandstone	10 ft.	......	......
Coarse grained grey sandstone	21 ft.	......	......
Shaly sandstone, carbonaceous sandy shale, and sandstone	74 ft.	......	......
Grey sandstone, with pebbly sandstone layers	124 ft.	......	......
Sandy carbonaceous shale and sandstone	60 ft.	......	......
Grey sandstone	30 ft.	......	......
Shaly sandstone and sandstone	42 ft.	......	......
Sandstone	36 ft.	......	......
Shaly sandstone and sandy shale	56 ft.	......	......
Dark grey sandstone	22 ft.	......	......
Newcastle formation.			
Dark blue, slaty (sandy) shale, with carbonaceous matter	37 ft.	......	......
Douglas coal seam.			

Summary record of bore-hole through Cranberry, Extension, and East Wellington formations and Wellington coal seam to Haslam formation, Cranberry district.

		Thickness. in feet.	Depth in feet.
Superficial deposits		20	20
Gravel, sand, and clay	20 ft.		
Cranberry formation		489	509
Sandy shale and shaly sandstone, and some sandstone and fine conglomerate	154 ft.		
Conglomerate	7 ft.		
Sandy shale and sandstone	30 ft.		
Conglomerate	19 ft.		
Sandy shale and shaly sandstone, and some sandstone and conglomerate	137 ft.		
Conglomerate	27 ft.		
Sandy shale and shaly sandstone, and some sandstone and conglomerate	105 ft.		
Extension formation		488	997
Conglomerate, chiefly coarse grained	51 ft.		
Shaly sandstone and sandy shale	8 ft.		
Coarse conglomerate	88 ft.		
Sandy shale and stone	23 ft.		
Conglomerate, chiefly coarse grained, with 2½ inch coal lens and 2 feet of sandstone	100 ft.		
Shale	2 ft.		
Coal (fairly persistent seam ?)	2½ ft.		
Sandy shale	16½ ft.		
Coarse conglomerate	45 ft.		
Sandy shale and sandstone	10 ft.		
Coarse conglomerate	14 ft.		
Sandy shale and sandstone	10 ft.		
Coarse conglomerate	118 ft.		
Wellington coal seam		3	1000
Coal with shale and sandstone partings			
East Wellington formation		49	1049
Sandstone, and fine conglomerate or pebbly sandstone, and some shale.			
Haslam formation			
Sandy shale.			

DETAILED DESCRIPTION OF FORMATIONS.

Benson Conglomerates.

DISTRIBUTION AND THICKNESS. The Benson conglomerate is the basal conglomerate of the Nanaimo series. It is exposed and apparently developed only locally—along the north and south shores of the ridge of crystalline rocks north of Departure bay, around the north flank of Mt. Benson, around the boss of crystalline rocks in the valley of the Nanaimo river near the western boundary of the map-area, and in the Haslam Creek canyon in the extreme southwestern part of the map-area. It is well exposed in all of these localities, but attains its greatest thickness and is best exposed in the

Haslam Creek canyon. Its thickness varies from nothing to about 400 feet, and averages about 100 feet.

LITHOLOGICAL CHARACTERS. Where it overlies the Vancouver meta-volcanics, the Benson formation varies from a fine to a typical coarse, basal conglomerate, the latter type being the most common. It is composed of subangular to well rounded waterworn pebbles and boulders of the green meta-andesites, characteristic of the Vancouver volcanics, firmly cemented in a greenish matrix composed largely of detritus of the volcanic rocks. The rock exposed in the Haslam Creek canyon is a rather fine grained conglomerate composed of subrounded to rounded fragments not only of the meta-volcanics, but of the slaty and sandy rocks of the Sicker series and of the Sicker gabbro porphyrite. Here, too, the conglomerate is interbedded with arkose-sandstones which grade upward into interbedded arkosic and shaly sandstones characteristic of the base of the overlying Haslam formation.

Haslam Formation (Marine Shales).

DISTRIBUTION AND THICKNESS. Overlying the Benson conglomerate and in places resting directly upon the underlying crystalline rocks is the Haslam formation, which is locally called the "marine shales" on account of the marine fossils which are found in the sandy shales composing the larger part of the formation. The Haslam formation extends along the western border of the map-area in an irregular belt from one-fourth of a mile to over 3 miles in width, and also underlies three narrow anticlines in the south central portion of the map-area. The rocks of the Haslam formation although they underlie some of the higher portions of the map-area are usually drift covered and the exposures are largely confined to the streams that have cut through the drift cover and into the Haslam rocks. The larger streams, especially Haslam creek, have cut deeply into the rocks, forming narrow canyons or gorges 100 to 300 feet deep, with in places nearly vertical walls.

Over the greater part of the map-area the thickness of the Haslam formation appears to be fairly uniform, ranging from

500 to 800 feet, averaging about 600 feet. In the northern part of the area, however, near Departure bay, the thickness of the rocks which are equivalent to the Haslam shales and which are placed in the Haslam formation, is less than 150 feet. It is probable that the Haslam shales would be exposed to the west of Departure bay if the drift cover were removed, as they are exposed farther west at Wellington; but they would not be more than 150 to 250 feet thick.

LITHOLOGICAL CHARACTERS. The Haslam formation is composed chiefly of thin bedded, light to dark grey, fine grained, arenaceous and frequently carbonaceous shales, which grade into fine grained, shaly or argillaceous, but siliceous sandstones. The shales usually weather concentrically and thus appear to have a concretionary structure. Also, especially in their lower portion, they contain very dense, hard, almost flint-like concretions, with a calcareous cement, that are 3 to 5 feet in diameter and about a foot thick. In places, more especially in the middle and lower portions of the formation, as is well exposed in the Haslam Creek canyon, thin beds of light grey, fine grained and often fairly siliceous sandstones are interbedded with the typical sandy shales. These sandstones average less than a foot in thickness and occur in great numbers, from 1 to 10 feet apart. The sandy shales are usually fractured and frequently contain more or less pyrite, which weathering to limonite, stains the shales yellowish brown, especially along the fractures and bedding joints.

Toward the base of the formation the interbeds of sandstone, although not more numerous, are thicker and usually of coarser grain. They grade into arkose or arkosic sandstones, which are interbedded with the shales. The arkoses either show rather abrupt transition into the Benson basal conglomerate or lie directly upon the underlying crystalline rocks. The arkoses vary in lithological character, some being composed largely of the detritus from the metamorphic volcanic and sedimentary rocks of the Vancouver group and others being composed largely of the detritus of the Saanich granodiorite. The latter resemble more or less closely the granodiorite. They are greyish green, medium grained rocks, composed of angular grains of quartz and feldspar, with flakes of biotite, in a greenish matrix. Under the microscope they are seen to contain the primary and secondary minerals of the granodiorite, and even the accessories, titanite and magnetite. The former are dark green, fine grained rocks, and contain in addition to quartz and feldspar, fragments of the dark, slaty and cherty rocks of the Sicker series and a large amount of chlorite, serpentine, and calcite. Some of the arkoses are carbonaceous, containing small carbonaceous and even bright coaly fragments. In a very few places, near the base of the Haslam formation, there are thin beds of sandy conglomerate.

The upper limit of the Haslam formation is usually the East Wellington sandstone and near this sandstone the Haslam formation consists, in places, of a dark, flaggy argillaceous sandstone. In the southern part of the map-area the Haslam formation appears to be directly overlain by the Extension conglomerates, and on Bush creek, near these conglomerates, there is at least one stratum of a fine conglomerate with a dominant, dark, carbonaceous and sandy matrix, interbedded with the typical Haslam sandy shales.

CALCARENITE. Near the shores of the ridge of Vancouver meta-volcanics north of Departure bay the basal conglomerates and the meta-volcanics themselves are overlain by a thin-bedded but coarse grained, and in places pebbly, olive green sandstone, that contains a large number of shell fragments. West of the biological station on the north shore of Departure bay, the shell-fragments or shell-sand compose about 65 per cent of the rock, the rest of the rock consisting of the detritus of the Vancouver meta-volcanics, the whole firmly cemented with calcite. There are also a few lenticular beds up to 4 inches thick of a fairly pure limestone composed of the shell sand. A partial analysis of the prevailing type is given below.

Insol. mineral matter	15·42
Ferric oxide and alumina	5·40
Lime	42·51[1]
Magnesia	0·94[2]

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[1] Equivalent to calcium carbonate 75·73.
[2] Equivalent to magnesium carbonate 1·96.
H. A. Leverin, analyst, Mines Branch, Department of Mines.

A rock such as this, composed of shell-sand, is known as a calcarenite, although in this instance the rock is an impure or sandy calcarenite. In order to distinguish between this peculiar rock and the rest of Haslam rocks it is shown by a different colour on the accompanying geological map, and is called the Haslam calcarenite.

East Wellington Sandstone

DISTRIBUTION AND THICKNESS. The upper portion of the Haslam formation almost invariably grades upward into, or is limited by a thin bedded or flaggy sandstone, called the East Wellington sandstone, which is usually the floor of the Wellington coal seam. It is well exposed only in a few localities, near the East Wellington colliery of the Vancouver-Nanaimo Coal Company and the old Jingle Pot slope in East Wellington, and to the southwest of Extension. It is shown on the accompanying map only where it is positively known to occur, but it is probable that it has a more wide-spread distribution. For example, it outcrops and is known to form the floor of the Wellington seam on the southwest side of the Extension (anticlinal) valley, but was not identified on the northeast side of the valley, although there is little question but that it occurs there. It varies in thickness from about 25 to 50 feet, averaging nearly 35 feet

LITHOLOGICAL CHARACTER. The sandstone is olive grey, weathering to brownish grey or yellowish brown, fine to medium and rather uniformly grained, and thin bedded and flaggy. It is composed chiefly of angular quartz grains, with some feldspar and light and dark mica in a brownish green matrix composed of calcite, chlorite, and serpentine, with an abundant calcareous cement. In a few places the sandstone contains thin interbeds of sandy shales, identical with the underlying Haslam shales. Less frequently the sandstone is coarse grained and contains thin interbeds of fine to medium grained conglomerate.

Wellington Coal Seam.

As stated, the East Wellington sandstone is the floor of the Wellington coal seam. The seam is overlain by the Extension formation, and in places has a roof of sandy shale and in others of conglomerate. The seam is well developed in the northern part of the map-area near East Wellington and in the central part from Harewood plains to the Nanaimo river. Between the two localities and south of the Nanaimo river its development is problematical.

Extension Formation.

DISTRIBUTION AND THICKNESS. The Extension formation, which consists chiefly of conglomerate underlies a broad belt with a N. 30° W. trend, extending entirely across the western part of the map-area, to the northeast of the Haslam formation. The belt averages somewhat over a mile in width, except in the central part, where, on account of narrow anticlinal areas of Haslam shales, and of a repetition of the beds of the Extension formation by folding and faulting, it is 2 to 3 miles wide. Except where covered by the Puyallup interglacial deposits north and west of Nanaimo, and by the Colwood sands and gravels, between Nanaimo river and [illegible] creek, the rocks of the Extension formation, more especially the conglomerates, are well exposed. They form cuesta-like ridges with steep rock cliffs at right angles to the bedding, and comparatively gentle slopes parallel to the bedding (see Plate III). These bedding or back slopes are covered in places with a few inches to a few feet of drift, but as a rule they are rather bare (see Plate IIIA). The thickness of the Extension formation varies from 500 to 1,000 feet, the maximum thickness being attained only in the southern part of the map-area. The average thickness is about 600 feet.

LITHOLOGICAL CHARACTERS. The Extension conglomerate, which makes up the greater part of the Extension formation, is a fairly uniform and characteristic rock, consisting of subangular to sub-rounded fragments, averaging about three-fourths of an inch in diameter, in a medium to coarse grained sandy matrix, the fragments and matrix being about equal in amount. The fragments are composed almost entirely of quartz, having been derived from quartz veins and from the very fine grained cherty and siliceous slaty rocks of the Sicker series. They are of various colours, greys, greens, browns, and reds. Fragments of the Vancouver meta-andesites are few. The matrix, which is greenish grey and brownish weathering, consists of a quartz and feldspar sand, in a fine greenish matrix composed of chlorite and biotite, the whole being firmly cemented by secondary quartz and calcite. In a few places the sandy matrix as well as the associated sandstones are concretionary. Toward the base of the formation, the conglomerate is finer grained, the pebbles are more rounded, and the matrix more abundant, and it grades into coarse grits and pebbly sandstones. There are numerous interbeds of coarse grained and gritty sandstones, especially in the lower part of the formation, and there are also a few horizons of sandstones and associated sandy shales or shaly sandstones, the thickest being about 80 feet. Associated with the latter rocks are a few thin coal seams and lenses. Although fairly persistent in places neither the coal seams nor the associated shaly rocks are persistent over large areas, and cannot be mapped independently. The base of the formation, which is the roof of the Wellington coal seam, is usually sandy shale, but in several places the conglomerate rests directly upon the coal. In the central and southern parts of the belt underlain by the Extension formation, sandstones and shales are confined to relatively thin interbeds in the typical massive conglomerate, although in the extreme southern portion, to the west of Ladysmith, the formation, which is there poorly exposed, appears to consist largely of greyish white, medium grained, siliceous sandstones. In the northern part of the belt, in the vicinity of East Wellington, the lower half of the formation consists largely of sandstones and shales, and the upper half consists almost entirely of massive conglomerate.

Cranberry Formation.

DISTRIBUTION AND THICKNESS. The Cranberry formation which overlies the Extension formation, outcrops along a belt extending from northern Newcastle island to Ladysmith. The width of the belt averages almost half a mile, but in the central part, west of South Wellington, the belt widens to over a mile, on account of repetition, owing to faulting and folding. The outcrops of the Cranberry formation are comparatively small and few. The formation is best exposed west of South Wellington and in the canyon of the Nanaimo river in Cranberry district. The thickness of the formation is variable and apparently ranges from 200 feet to nearly 600 feet. In its northern portion it averages about 250 feet and in its central and, possibly, southern portion it averages about 500 feet.

LITHOLOGICAL CHARACTERS. The prevailing rocks of the Cranberry formation are concentric weathering, dark green, thin bedded, flaggy or shaly sandstones of fine to coarse grain, and in places gritty or pebbly. They are composed of small subangular fragments of the slaty, cherty, and volcanic rocks of the Vancouver group and finer grains of quartz and feldspar in a greenish matrix of volcanic rock débris, consisting of chlorite, epidote, biotite, sericite, and magnetite. The cement is limonite and secondary quartz. Interbedded with the flaggy and shaly sandstones are numerous beds of sandy shale, similar in composition to the sandstones. Both the sandstones and shales are carbonaceous in places and contain a few obscure plant impressions and remains. In the middle and lower portions of the formation are fine sandy conglomerates and grits. Some of the conglomerates resemble the Extension conglomerate, but as a rule the matrix is more abundant and pebbles of the Vancouver meta-andesites are more numerous. The individual beds of conglomerate are thinner than those of the Extension formation, 25 feet being a maximum, and there are more interbeds of sandstone. The lower part of the formation grades more or less perfectly into the Extension conglomerate. In most places the transition zone is thin and fairly well defined, but in other places, as near the Nanaimo river, it is not well defined. In mapping, the first bed of massive conglomerate over 25 feet in thickness is taken as the top of the Extension formation.

At the north end of Newcastle island is a pebbly conglomerate with numerous sandstone interbeds and lentils. The conglomerate consists of small rounded fragments of chert and meta-andesite and the fragments predominate over the matrix. The sandstone is fine grained and rather quartzose. The conglomerate and sandstone are very conspicuously cross bedded. These rocks are overlain and perhaps underlain by thin bedded shaly sandstones characteristic of the Cranberry formation. The origin and proper correlation of this mass of conglomerate and sandstones, which may be lenticular in shape, are doubtful, but it is mapped as a part of the Cranberry formation.

Newcastle (Lower Douglas) Coal Seam.

The upper limit of the Cranberry formation is the Newcastle coal seam, or as it is sometimes locally called, the Lower Douglas seam. The seam is overlain by the rocks of the Newcastle formation. It is well defined in the northern and central part of the Nanaimo map-area, and its position can be fairly well located. It is poorly defined in the southern part of the map-area and may be absent, and even south of Chase river it is of doubtful commercial thickness and quality.

Newcastle Formation and Douglas Coal Seam.

DISTRIBUTION AND THICKNESS. The Newcastle formation, which contains the Douglas coal seam, directly overlies the Newcastle coal seam. The formation outcrops along a belt, averaging less than half a mile wide, extending from northern Newcastle island, through the city of Nanaimo and the town of South Wellington to Ladysmith. Except where covered by the Colwood sands and gravels the outcrops of the formation are fairly numerous,and its upper contact with the Protection sandstones is very well defined in most places. The thickness of the formation varies from 125 to possibly 400 feet, and averages about 175 feet. In the vicinity of Nanaimo, where it is composed chiefly of grit, it is about 250 feet thick, but on Newcastle island and near South Wellington where the formation consists largely of shaly sandstones and sandy shales, it approaches its minimum thickness of 125 feet. It reaches its maximum thickness, not well determined, only in the extreme southern part of the map-area.

The Douglas coal seam occurs in the Newcastle formation about 25 to 100 feet above the Newcastle seam, and from 50 to perhaps 250 feet below the top of the formation. The seam is well developed from northern Newcastle island to south of Nanaimo river, the outcrop of the seam crossing the river near the Esquimalt and Nanaimo Railway bridge at Cassidy. Indications of the seam also occur as far south as Bush creek, a mile north of Ladysmith. The seam is well defined and there are exposures at the following places: on the east and west coasts of Newcastle island, at the Brechin mine, in Nanaimo, north of Chase river, in the vicinity of South Wellington, and near the Nanaimo river. Farther south there are no good exposures, but since the seam is so well developed near Nanaimo river and since outcrops of coaly shale with coal lentils occur at about the coal horizon in Bush creek, where crossed by the Extension railway of the Canadian Collieries Company, the southward extension of the seam is assumed. The roof and floor of the seam vary from grit to sandy shale, corresponding fairly closely to the similar variation in the lithological character of the Newcastle formation. The former conditions prevail in the vicinity of Nanaimo, and the latter at South Wellington and at the Brechin mine.

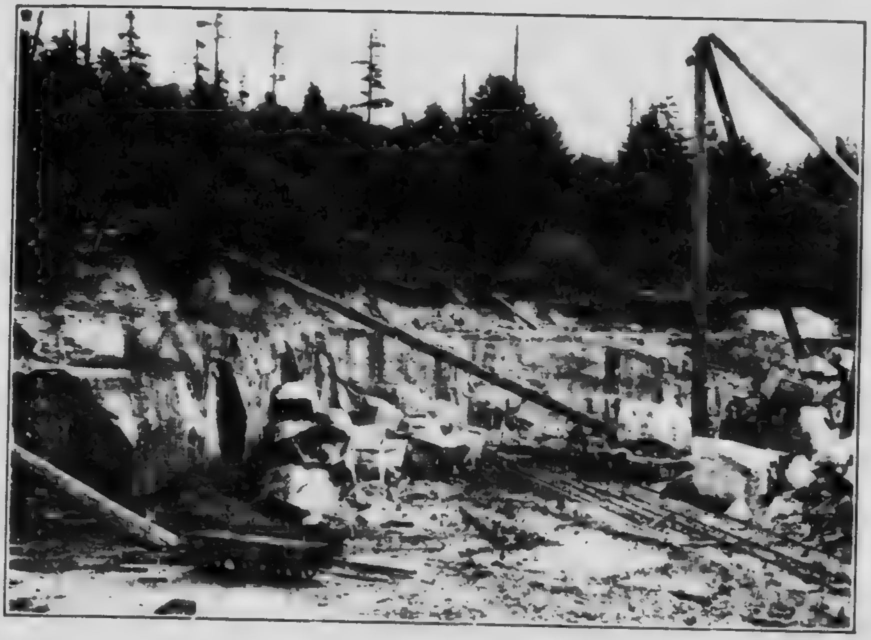
LITHOLOGICAL CHARACTERS. The rocks of the formation vary somewhat, although usually having determinative characteristics. The most characteristic and abundant rock is an olive green, brownish weathering, and in a few places, cross-bedded, grit. It is composed of small angular to rounded chiefly subrounded fragments, 1 to 5 mm. ($\frac{1}{16}$ to $\frac{3}{16}$ inches) in diameter, of cherty or slaty rocks and meta-andesites in a sandy matrix, which is in small amount, composed of angular quartz and feldspar grains, and some biotite and chlorite. It is cemented rather weakly by limonite. In the grit are a few rather thin beds of conglomerate of a similar composition. In places, as in Nanaimo, almost the entire formation, with the exception of a few interbeds of thick to thin bedded, medium to fine grained sandstone consists of the grit. In other places, as northern Newcastle island and near South Wellington, the formation consists largely to almost entirely of dark green, concentric weathering sandy shales and thin bedded, shaly sandstones, that are composed largely of detritus of the Vancouver meta-volcanics. Interbedded with these shaly rocks are, however, lenses of the characteristic grit, and in most localities where the shaly rocks predominate the grits form at certain horizons fairly thick strata. The rocks, more especially the sandy shales, are in some portions carbonaceous, containing many so-called "coal markings" and even coaly fragments.

Protection Formation.

DISTRIBUTION AND THICKNESS. The Newcastle is overlain by a formation composed chiefly of a characteristic sandstone, which is the best horizon marker in the Nanaimo series. The formation is called the Protection from its typical development on Protection island. It underlies a belt extending from Newcastle island to Ladysmith, 1 to 1½ miles wide in the northern part of the map-area and narrowing in the extreme southern part, where the dips are high, to less than one-fourth of a mile. The formation is also exposed 4 miles east of the main belt on Round island, a small island 1½ miles southeast of Dodd narrows, in Trincomali channel, which follows an anticline. The Protection sandstone is fairly well exposed, forming small but numerous outcrops. The lower, western contact of the formation can be fairly well determined. The upper contact with the Cedar District shales is transitional in character and rather indefinite, and can be well located only where it crosses the Nanaimo river. The formation is more uniform in thickness than most of the others, varying from 600 to 750 feet, and averaging about 650 feet.

LITHOLOGICAL CHARACTERS.—The formation consists chiefly of a greyish white, fine to medium and uniformly grained sandstone, consisting of subangular grains of quartz or of quartzose rocks and clear or white weathered feldspar, shreds of biotite and some white mica, and a few green and red grains of other minerals. Under the microscope the rock is seen to consist largely of granodiorite detritus: both orthoclase and plagioclase feldspar are present, while the accessory and secondary minerals include, besides those mentioned, epidote, chlorite, magnetite, and kaolin. The cement is chiefly secondary silica, and is not always sufficient to bind the rock firmly. The sandstone is thick to thin bedded and in places is even flaggy, but the thick beds are most common (see Plate VI A). Some beds are cross stratified and even concretionary, and weather in a concentric or honeycombed fashion. Although usually greyish white, weathering to a dirty or brownish grey, some beds are slightly ferruginous and have a yellowish grey colour on fresh fracture, and a brown weathered surface. In several places,

PLATE VI.



A

B

A. Quarry in Protection sandstone, Newcastle island, showing single bed, 16 feet thick.

B. Quarry in DeCourcy sandstone, Jack point, showing thick bedded sandstone with thin bedded and shaly sandstone.

especially toward the middle portion of the formation, the sandstones are coarse grained and pebbly and pass into fine conglomerates with well rounded fragments of quartz and quartzose rocks. Interbedded with the sandstones are fairly numerous rather thin beds of olive grey, shaly sandstones, and of darker, carbonaceous, siliceous, sandy shales. These beds are more numerous and thicker in the upper part of the formation and are transitional into shales of the overlying Cedar District formation. There are also, usually associated with the shaly interbeds, small coal lenses up to a foot in thickness, none of which are of commercial value.

Cedar District Formation.

DISTRIBUTION AND THICKNESS. Overlying the Protection is a formation consisting chiefly of shaly rocks called the Cedar District formation.[1] This formation, which is the least resistant, underlies a wide valley with a nearly north-south trend, extending from the mouth of the Nanaimo river to Ladysmith (Oyster) harbour, the larger part of the valley occurring in Cedar district. The formation is also exposed 2 to 3 miles to the east, on the shores of Vancouver and Mudge islands south of Dodd narrows, occurring on the limbs of the anticline underlying Trincomali channel. The upper part of the formation is well exposed along the shores at the latter places, but in the valley the formation is largely drift covered. There are, however, several small scattered outcrops, and portions of the formation are fairly well exposed at a few places along the Nanaimo river. Therefore, although the contacts of the formation, which are both transitional and rather indefinite, can not be accurately located, the general position and shape of the outcrop of the formation can be fairly well determined. The thickness of the formation, like that of the Protection formation, is fairly uniform, and varies from 700 to possibly 1000 feet in its southern portion, averaging about 750 feet.

LITHOLOGICAL CHARACTERS. The formation consists chiefly of dark grey, concentric weathering, carbonaceous and ferruginous, fine sandy shales, with a great number of thin (1 to 3 inches) interbeds of brownish grey, rather fine grained sandstones. In the shales are nodules or concretions of sandstone, up to 6 feet in diameter and 1 foot thick, which are cracked and filled with hardened mud. There are also several rather thick (1 to 20 feet) beds of yellowish grey, medium to coarse grained, sandstones. These are in places concretionary, cross-bedded, and ripple marked. The thick beds of sandstone are more numerous in the upper part of the formation, and in the overlying DeCourcy formation they greatly predominate. The shales are not only interbedded with sandstones, but are cut by a large number of sandstone dykes up to 3 or 4 feet in width (see Plate VII A.)[1]

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[1] The name Cedar has already been used to designate a formation of Jura-Triassic age in California.

DeCourcy Formation.

DISTRIBUTION AND THICKNESS. Overlying the Cedar District shales is a thick and fairly uniform formation of sandstones, called the DeCourcy formation from its typical development in the DeCourcy group of islands. The DeCourcy formation extends from Jack point, a long narrow point east of Nanaimo, along the east coast of Vancouver island to the high range of hills, called the Woodley range, on the east side of Ladysmith (Oyster) harbour. The formation also forms the greater part of Mudge, Link, and DeCourcy islands of the DeCourcy group, on the northeast side of Trincomali channel. The two areas, which join at Dodd narrows, outcrop in the two limbs of the Trincomali anticline. The outcrop in the northeast limb averages less than half a mile wide, but on account of a number of open folds the outcrop in the southwest limb varies from 1½ to 4 miles. The rocks of the formation are very well exposed since they form numerous cuesta ridges. The contacts of the formation, however, can only be accurately located in a few places, but the general position and extent of the outcrop can be well determined. Over the largest part of its extent the formation is about 900 feet thick, but in the Woodley range the thickness increases to 1,400 feet.

LITHOLOGICAL CHARACTERS. The prevailing rock of the formation is a greenish grey, yellowish brown weathering, fine to

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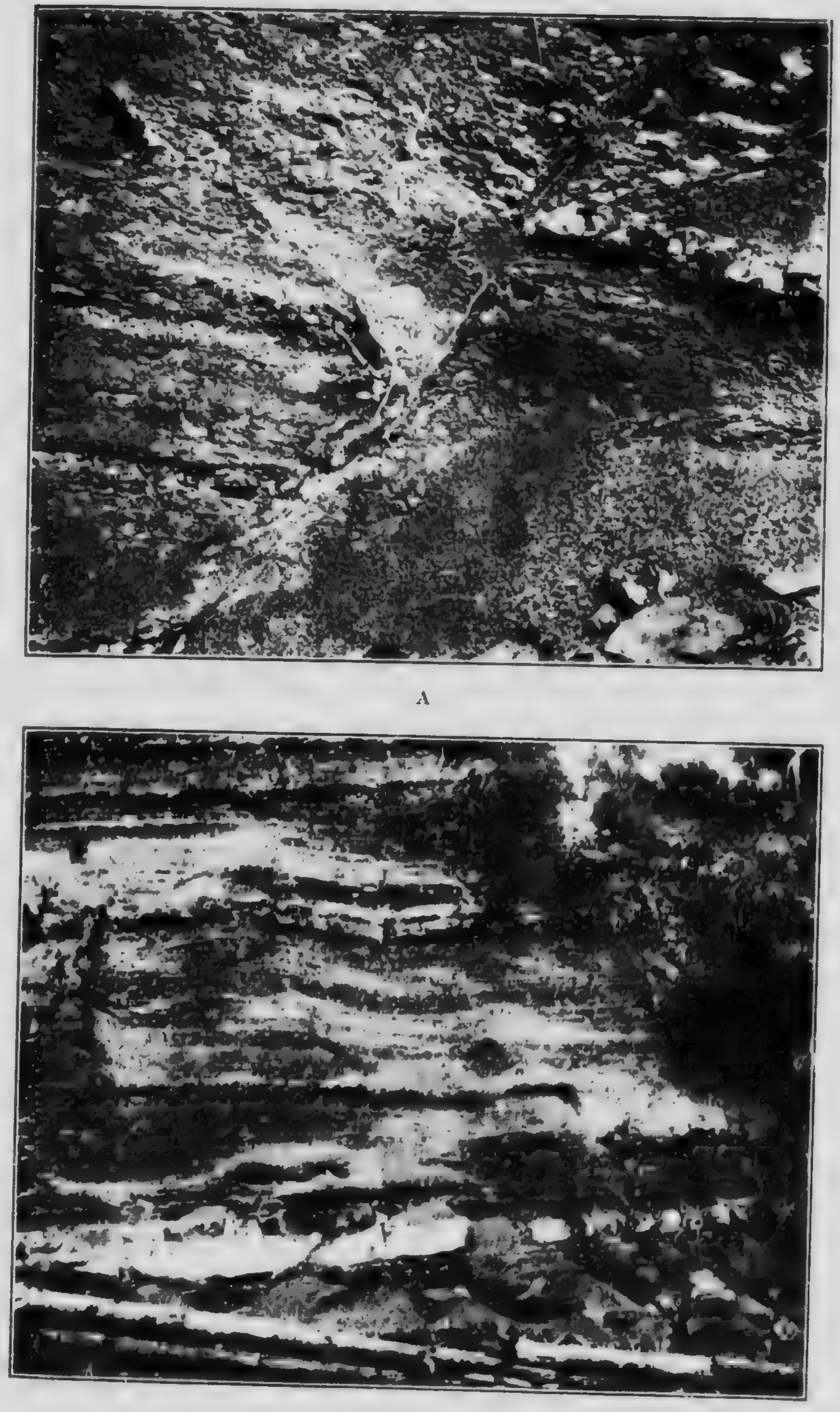
[1] The sandstone dykes of both the Cedar District and Northumberland shales are treated in more detail under "Structural Geology of the Nanaimo series."

PLATE VII.



A. Cedar District shales. Nanaimo river, showing fault and small sandstone dyke. (Dyke extends from the centre of the plate to the upper left hand corner.)

B. Upper Northumberland shales, Descanso bay, Gabriola island; showing numerous thin, sandstone interbeds.

coarse grained, gritty, and even pebbly sandstone composed of angular grains of quartz, feldspar, and meta-andesite, and shreds of muscovite and biotite, in a greenish matrix composed chiefly of chlorite. It is seen microscopically to contain also magnetite, titanite, and epidote. Its cement is siliceous and ferruginous. It is chiefly thick bedded, but there are many thin bedded and even flaggy or shaly bedded portions (see Plate VIB). The sandstone is frequently cross-bedded and concretionary. Some of the concretions are very large, having a maximum diameter of 10 feet. They are frequently fissured and filled with indurated mud or fine sand, but in many places, when exposed to weathering the fissure filling has weathered out. The concretions themselves frequently weather out, leaving round holes in the sandstone. The sandstone also weathers into "galleries"[1] with honeycombed surfaces. In the Woodley range the sandstones are as a rule very coarse and pass into conglomerates with large subangular to well rounded fragments, averaging over an inch in diameter, of quartz, meta-volcanics, granodiorite, and granodiorite porphyrites, in a sandstone matrix, which predominates. Interbedded with the sandstones are relatively thin beds, a few inches to 2 or 4 feet in thickness, of darker, carbonaceous sandy shales and shaly sandstones, and in a few places these beds contain lenses of coal. These shaly interbeds are more numerous in the lower and upper portions of the formation, which is transitional into the Cedar District shales below and the lower shales of the Northumberland formation above. The transitional zones 100 to 200 feet thick consist of interbedded shaly sandstones or sandy shales and thick bedded sandstones, in about equal amount. The first bed of coarse sandstone 20 feet or more in thickness, is considered as the bottom or top of the DeCourcy formation.

Northumberland Formation.

DISTRIBUTION AND THICKNESS. Overlying the De Courcy formation is a very heterogeneous formation which is, however, limited at its top and bottom by beds of sandy shale. The bottom shale persists throughout the Nanaimo basin and the

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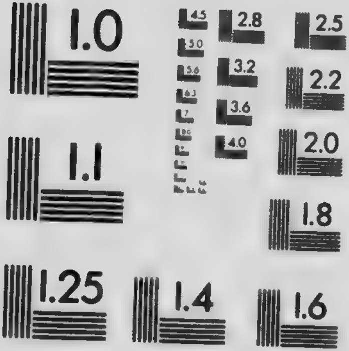
[1] See more complete description under Gabriola formation.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



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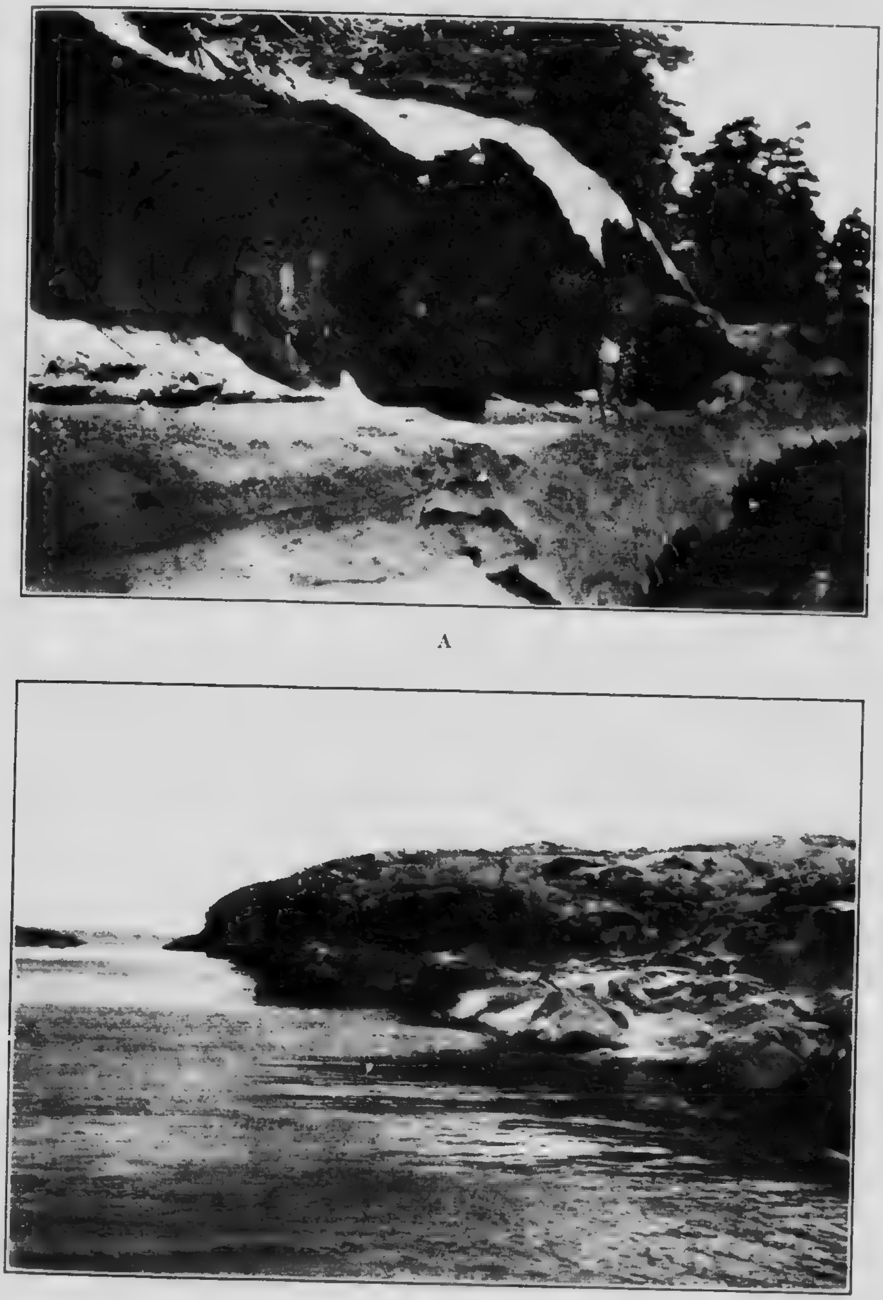
upper shale persists throughout the Nanaimo map-area, although to the southeast it is absent in places. Within the Nanaimo map-area the formation, which is called the Northumberland formation, since it is best exposed along the northeast shore of Northumberland channel on the southwest shore of Gabriola island, is virtually confined to Gabriola island, and outcrops along the northeast and southwest coasts of the island, which is a synclinal ridge. However, the formation is shown on the accompanying map as underlying a small area in the southeast part of the map-area, south of Kulleet bay. The hard rocks in this vicinity are entirely drift covered, but from the information on hand concerning the thickness and structure of the underlying DeCourcy formation, the Northumberland formation must outcrop below the drift in this vicinity. The width of the outcrop is only from one-fourth to a little more than one-half a mile wide, a portion of the formation coming to the surface only below sea-level. However, in the False narrows, between Gabriola and Mudge islands, several outcrops of this portion of the formation are exposed at low tide. It is the reefs formed by these outcrops that makes the False narrows too dangerous to be used as a channel. The rocks of the formation are well exposed along the shores of Gabriola island, and the upper contact of the formation can be determined with considerable accuracy. The lower contact is below sea-level, although it can be fairly well located a few feet from the northwest shore of Mudge island, in False narrows. The thickness of the formation varies from about 1,100 to 1,200 feet.

LITHOLOGICAL CHARACTERS. The formation consists of shales, sandstones, and conglomerates. As already mentioned the shales occur at the top and bottom of the formation, and are virtually confined to those horizons. The shales are very similar to those of the Cedar District formation, although they are, as a rule, less carbonaceous. They are grey, thin bedded, and sandy, and contain numerous beds 2 to 6 inches thick, of yellowish grey, fine to medium grained, siliceous sandstones (see Plate VIIB), and a few interbeds of coarser grained sandstone, up to 8 feet thick. Like the Cedar District shales they are cut by a large number of sandstone dykes, which are especially well exposed on the northeast shore of Gabriola island. In the upper



A

B

A. Galiano (Malaspina) gallery, Gabriola island; showing the effect of wind erosion of the Gabriola sandstone, its cement having been partially dissolved by salt water spray.

B. West shore of Snake island, cliffs 25 feet high; showing the effect of wind erosion of the Gabriola sandstone.

portion of the lower shales, which are about 500 feet thick, the shales, both in vertical and lateral directions, grade irregularly into or, more strictly, are replaced by sandstones and coarse conglomerates, the thickness of the sandstone-conglomerate portion of the formation being about 400 feet. The sandstones are similar to the coarse grained, thick bedded sandstones interbedded with the shales, and to those of the De Courcy and overlying Gabriola formations. They are thin to thick bedded, yellowish grey, fine to coarse grained, and concretionary. On Gabriola island the conglomerates occur as interbeds in the sandstones up to 30 feet or more in thickness, but to the southwest of the Nanaimo map-area, for example on Galiano island, they are in places nearly 1,000 feet thick, comprising the greater portion of the formation. The conglomerates consist of fragments of virtually all the crystalline and metamorphic rocks of Vancouver island—vein quartz, cherty and schistose rocks of the Sicker series, granodiorite and diorite, porphyrites, meta-andesites, and even limestones and sandstones. The fragments are well rounded, and are up to 8 inches in diameter, averaging over 1 inch in diameter, and greatly predominate over the sandstone matrix.

Gabriola Formation.

DISTRIBUTION AND THICKNESS. Overlying the Northumberland formation and composing the larger part of Gabriola island is the uppermost formation of the Nanaimo series, composed chiefly of sandstones and called the Gabriola formation. With the exception of two small islands, Snake and Entrance islands to the north of Gabriola island, the Gabriola formation is restricted within the Nanaimo map-area to Gabriola island. The rocks are fairly well exposed, especially along the shores, but in the interior of the island they have been mechanically disintegrated and are now covered by a thin mantle of rock debris. In the Nanaimo map-area the thickness of the formation is about 1,400 feet, but to the southeast the thickness increases to 3 [illegible] feet.

LITHOLOGICAL CHARACTERS. The Gabriola formation consists chiefly of thin to thick bedded, yellowish grey, fine to medium grained, sandstones composed chiefly of angular grains, 0·1 to 2 mm in diameter, of quartz, feldspar, and meta-volcanics, and flakes of biotite in a greenish matrix composed of chlorite, serpentine, epidote, and magnetite, cemented largely by calcite. The sandstones are concretionary (see Plate XIII), the concretions averaging 1 to 3 feet in diameter, and cross-bedded in places. The concretions weather out leaving holes and where the sandstones are subject to wind and to some extent to wave erosion, especially along the shores where the calcareous cement has been partially dissolved by salt-water spray, the sandstones have been carved into hemispherical and hemi-cylindrical caves or as they are locally called, "galleries." The best known of these galleries is Galiano (or Malaspina gallery) in the northwest part of Gabriola island, which was first described by one of the early Spanish explorers, either Galiano or Malaspina, but those of the west shore of Snake island are, although smaller, even more fantastic (see Plate VIII). In places the walls of the gallery are smooth, but in other places the sandstone is of unequal resistance and has been carved into fantastic shapes with lacework and honeycomb patterned surfaces (see Plate IX). The walls of the galleries are disfigured with names and dates painted on the sandstone, but they serve to measure the rate of erosion or abrasion of the sandstone, since there is little abrasion where the sandstone is covered with paint. The painted letters and figures are, therefore, "raised" to a greater or less degree dependent upon their age. In places, those only six months old stand out 1 mm (over $\frac{1}{32}$ of an inch or more) from the unpainted surfaces, while those 2 or 3 years old stand out for 3 or 4 mm ($\frac{1}{8}$ of an inch or more.) When they reach this stage the letters and figures are rapidly destroyed. It is thus seen that where most exposed the sandstone is eroded at a rate of nearly 2 mm a year.

Interbedded with the sandstones are numerous beds of grey, fine grained, shaly sandstones and even dark, bluish grey but rusty weathering sandy shales, which are in a few places more argillaceous. In the middle part of the formation the shaly beds although fairly numerous are thin, seldom more than a foot thick, but in the upper 500 feet they are fairly thick and predominate. In the lower 100 feet they are also thicker and this portion of the formation forms a transitional zone into the

PLATE IX.

A

B

A. Fantastic wind eroded forms in Northumberland sandstone, southwest shore of Gabriola island.

B. Honeycomb weathering of Gabriola sandstone on Entrance island.

underlying Northumberland shales. The contact of the two formations is placed at the contact of a 75 foot bed of sandstone overlying a 50 to 60 foot bed of shale.

STRUCTURAL RELATIONS OF THE NANAIMO SERIES.

Internal.

FOLDING. The rocks of the Nanaimo series have as a whole a general northwest-southeast strike and a prevailing dip to the northeast. At the northern rim of the basin, in the vicinity of Departure bay, the general strike turns to the northeast and east, while the dip is to the southeast and south. Besides this major fold, which outlines the basin, there are many smaller folds. Nearly all the folds have a general northwest-southeast axis, parallel to the major fold, and many of them, especially the minor folds, pitch and flatten out to the southeast. The larger and most important of the smaller folds are, beginning in the southwestern part of the map-area and proceeding to the northeastern part, the Extension anticline, the Kulleet syncline, the Trincomali anticline, and the Gabriola syncline.

Extension Anticline. The Extension anticline, which may be traced for nearly 6 miles, trends N. 35° W., and extends from the northwest of the town of Extension to southeast of the Nanaimo river. The anticline is open but rather sharp, the limbs dipping away from the axis at angles ranging from 10 to 50 degrees. As is so commonly the case, erosion has progressed most rapidly alo[illegible] [illegible]is of the anticline, forming a valley, which may be cal[illegible] [illegible]tension valley, in the Haslam shales. On either si[illegible] [illegible]alley the limbs of the anticline composed of the up[illegible] [illegible]n of the Haslam shales, the East Wellington sandstone, the Wellington coal seam, and the lower portion of the Extension conglomerates, form cuesta ridges with their steep front slopes bordering the valley. Over a mile southeast of Nanaimo river the Haslam shales pitch below the Extension conglomerates and the anticline can be traced only a little farther.

Kulleet Syncline. The Kulleet syncline is a rather broad open syncline of varying trend, chiefly in the DeCourcy sandstones. It extends across Cedar and Oyster districts from the northwest of Holden lake to Kulleet bay, a distance of about 10 miles. The trend of the axis varies from N. 45° E. to N. 80° W., but the average trend is N. 30° W. The limbs dip at angles ranging from 5 to 30 degrees, the average dip being about 12 degrees. There are two low places or basins in the syncline, one to the south of Holden lake and the other at Kulleet bay. The latter basin pitches rather steeply to the southeast. A small transverse roll separates the northern end of the Kulleet syncline from a smaller syncline, in the Cedar District shales and Protection sandstones, extending from the mouth of Nanaimo river to Stovely, that is virtually a continuation of the Kulleet syncline.

Trincomali Anticline. The Trincomali anticline is an open but fairly sharp anticline, trending N. 40° W. At its northern end near Dodd narrows it pitches rather steeply to the northwest; to the southeast it extends for several miles beyond the Nanaimo map-area. It has been eroded along the axis, which is now largely under water, below Trincomali channel. However, at one place on Round island, the Protection sandstone is exposed near the axis. The limbs of the anticline, consisting of the Cedar District shales and the DeCourcy sandstones, dip about 20 degrees. The northeastern limb forms the DeCourcy islands, and the southwestern forms several small ridges along the shore of Vancouver island.

Gabriola Syncline. The Gabriola syncline is a broad open syncline in the Northumberland and Gabriola formations, and the rocks involved compose Gabriola island. The axis, which extends through the centre of the island, varies in trend from nearly due north at its northwestern end to N. 80° W. at its southeastern end, the average trend being about N. 55° W. The limbs dip at angles ranging from 5 to 25 degrees, the average dip being about 15 degrees. Near the northern end of Gabriola island the syncline is crossed by a transverse anticlinal roll, so that the northwestern part of the syncline pitches to the north and the southeastern part pitches to the southeast.

Minor Folds. Besides the larger folds just described, there are many smaller folds, the larger and better exposed of which are shown on the accompanying maps. The Haslam formation wrinkles at several places where it has been shoved by the

Extension conglomerates against the crystalline rock base. Folds are well exposed, north of Mt. Benson, along Berkeley creek, and along Haslam creek and its North Fork. There are doubtless many other folds which are not exposed. The folds are invariably longitudinal, with a northwest southeast trend and are not persistent. They are as a rule open, with gently dipping limbs, but near Haslam creek, north of Mt. Hayes, the Haslam shales directly underlying the Extension conglomerates are involved in several sharp folds with steeply dipping limbs.

Southwest of the Extension anticline the Extension formation is involved in several rather large folds and along the axes of two of them the Haslam formation is exposed. They are all longitudinal and, with two exceptions, they are open with gently dipping limbs. The two exceptions are a syncline and an anticline directly southwest of the Extension anticline and extending from Nanaimo river to Haslam creek. These folds are sharp, the limbs dipping at angles ranging from 25 to 55 degrees. Also, northeast of the Extension anticline, along the Nanaimo river and east of the town of Extension, there are a few folds in the Extension formation. Besides the larger folds there are, especially in the shaly beds of the Extension formation, several small sharp rolls.

The Cranberry and Newcastle formations are, with the Extension formation, involved in two fairly large, open, and southeastward pitching longitudinal folds near the Nanaimo river, a syncline and corresponding anticline. Much smaller folds, but also longitudinal and southeastward pitching, occur in the Cranberry and Newcastle formations to the west of South Wellington, and in the city of Nanaimo, south of the Canadian Pacific Railway Company's wharf, northeast of the railway station, and south of Victoria circle. On northern Newcastle island an anticline and syncline cross the island with a general N. 60° E. strike.

The Protection sandstones are folded at several places into small longitudinal, and southeastward pitching folds, and near the Nanaimo river at Stovely, are two fairly large folds. The western is, as mentioned, virtually the continuation of the Kulleet syncline, and the eastern, which is an open anticline, extends for over 2 miles to the east in the Cedar District and DeCourcy formations.

The Cedar District formation, the least resistant of the entire series, has been warped into several small folds or contortions, some of which are transverse, as those crossing the Nanaimo river south of Stovely. Few of these folds can be traced for more than a few feet and consequently are not shown on the accompanying maps.

The De Courcy sandstones are involved in several fairly large broad, open, longitudinal folds between the Kulleet syncline and the Trincomali anticline. Two of these, an anticline and a corresponding syncline, extend from near Greenway lake, south of Boat harbour to beyond Yellow point, a distance of over 4 miles.

With the exception of the transverse anticline which crosses the Gabriola syncline the Northumberland and Gabriola formations are not involved in any minor folds. Near the axes of the Gabriola syncline and the transverse anticline, however, the rocks, especially the Northumberland shales, are crumpled and sheared.

FAULTING. The Nanaimo series are broken by only four faults of any great size but there are many minor faults, most of which are really sharp rolls with a very small actual displacement. The larger faults are all strike faults and presumably all reversed or compression or thrust faults. The largest fault occurs about three-fourths of a mile southwest of the Extension anticline, striking about N. 35° W. parallel to the anticline, and it may be traced for 3½ miles, although in its southern part, southwest of Panther ridge, it merges for half a mile into a sharp crestal anticline. Along the fault the rocks dip to the southwest at angles of 10 to 25 degrees, the fault dips steeply in the same direction, the southwestern side of the fault is the upthrown, and the maximum displacement appears to be nearly 500 feet. As a whole, the dip of the fault is nearly vertical, a fact which is well determined since the fault is cut by the "tunnel" or adit of the Extension collieries about 300 feet vertically below its outcrop, the rocks of the downthrown side turning abruptly up against the fault plane. But it appears, from mining, that the fault surface is warped, so that in places the dip is comparatively low to the southwest, the fault in these places being of the nature of an overthrust. Along the outcrop of the fault the Haslam shales on the southwestern and upthrown side are in contact with the Extension conglomerates of the downthrown side. A pronounced but narrow valley has been cut in the shales, and to the southwest the upthrown Extension conglomerates, capping the Wellington coal seam, form a cuesta ridge with a very steep front slope or fault-line scarp bordering the valley (see Plate IIIB).

Half a mile to the southwest of the northern part of the fault described above, is a similar but smaller fault. It strikes nearly N. 35° W., dips steeply to the southwest, and the southwestern side is the upthrown. The fault has a maximum displacement where it is best exposed on the surface, near the old No. 1 mine of the Wellington Collieries Company, of 100 to 150 feet. The displacement decreases to nothing to the southwest, the fault being traced in the underground workings of the No. 3 Extension mine.

The two other large faults are problematical, but their presence is virtually assured by the sequence of beds as exposed on the surface and by the depth of the Wellington seam as determined by boring. These occur to the northeast of the Extension anticline and break the northeastward dipping rocks of the Extension and Cranberry formations. One, 2 miles long, extends from Harewood plains to a large swamp a mile northeast of the town of Extension, the other, 1½ miles long, occurs to the west of South Wellington in the Richard Lake, Cranberry Lake valley. Both faults have a general N. 20° W. strike, the dip is probably to the northeast, the northeastern side is the upthrown, and the maximum throw varies from near 200 feet in the Harewood Plains fault to 300 feet in the fault west of South Wellington.

Small minor faults, both longitudinal and transverse, were noted especially in the weaker rocks, the Haslam and Cedar District shales (see Plate VII A), near the axes of the sharper folds, but on the east shore of Newcastle island the Protection sandstones are broken by a small fault, striking N. 10° W., with a vertical dip, the western side being upthrown about 15 feet. Bedding faults, well exposed in the Haslam

Creek canyon, have taken place where the Nanaimo series has been thrust against the crystalline rock base. It is probable that the contact between the Extension conglomerates exposed at the northeast angle of Departure bay and the Vancouver volcanics is also a fault.

What are most probably sharp rolls are locally called faults. The best known of these occur near the shore in the southern part of the city of Nanaimo, west of No. 1 mine of the Western Fuel Company, and along the Nanaimo river, near Stovely, and near the bridge of the Pacific Coast Collieries' railway.

A few sharp rolls occur in the upper formations of the Nanaimo series where the rocks are otherwise only moderately disturbed, that apparently took place while the rocks were still soft and plastic. These rolls, which are really more of the nature of small displacements or faults, are so pronounced that a bed which has a moderate dip in one direction may turn down abruptly at right angles, so that the dip of the downturned portion is vertical and its strike is at right angles to the strike of the bed as a whole. The largest of these sharp rolls, exposed on the west shore near the northern end of Newcastle island, occurs in a coarse grained thick-bedded conglomerate of the Cranberry formation, and the width of the down-turned portion is about 150 feet. The general strike and dip in this locality is N. 35° E., 20° S.E., while the attitude of the downturned portion is N. 55° W., 85° S.W. Another, smaller roll occurs along the shore at Nanaimo, north of the post-office, in the Douglas grit. There the general attitude is N. 35° W., 20° N.E., and the attitude of the downturned portion, which is about one foot wide, is N. 85° W., 80° N.E. In spite of the abruptness and magnitude of the displacement, there is not the slightest indication of extra jointing, shearing, or slickensiding. Instead, the folds have occurred as if the rocks were as plastic as wet clay. Hence, unless we hypothecate more intense folding than is observed and a much thicker cover, which would induce greater pressure, this type of fold can be explained only by the supposition that the conglomerates and grits and other sediments which have suffered in the same way, were soft and plastic when the folding took place.

SANDSTONE DYKES. The sandstone dykes of the upper shales of the Nanaimo series also indicate that movements took place while the sediments of at least the upper part of the series were still soft. The dykes are numerous in the shales of the Northumberland and Cedar District formations (see Plate VII A) especially in those shales characterized by a large number of thin sandstone interbeds. They are best exposed in the Cedar District shales on the shore of Vancouver island south of Dodd narrows and in the Northumberland shales on the northeast shore of Gabriola island. The dykes are fairly regular and the larger dykes, those 3 to 4 feet thick, may be traced for at least 100 feet. Along the shores, on account of their greater resistance to wave erosion, they stand above the shales, forming low walls, the highest wall noted being 3 feet. These walls project into the water for some distance, and there is an instance in the Comox district of one being utilized as a pier for a small boat.

As a rule the dykes are finer grained than the sandstone interbeds and the cementing material is more calcareous, but in general the two are of similar material. The dyke rocks are greyish white, fine grained sandstones composed chiefly of angular grains of quartz and feldspar, shreds of biotite and muscovite, with accessory magnetite, titanite, garnet, chlorite, pyrite, and in some of the dykes carbonaceous matter, the whole firmly cemented by a fairly large amount of calcite. Although fairly regular, the dykes branch and are offset by small faults. Some dykes protrude from the sandstone interbeds and there are off-shoots from the dykes conformable with the bedding of the shales that simulate the appearance of sandstone interbeds, but are recognized by occurring usually on one side of the dyke only. The dykes cut the shales sharply, apparently along joint planes, and the shales are frequently bent or slightly contorted next to the dykes. There are also small and irregular off-shoots from the larger dykes into the shales that resemble small apophyses from an igneous dyke.

From their occurrence and close resemblance to intrusive sandstone dykes in California, which have been fully described by Diller[1] and Newson[2], the origin of the dykes is in little question. They appear to have been formed by the injection of soft sands, which were forced usually upward along joint planes in the shales, the injection being similar to that of an igneous dyke. After the injection the sands were firmly cemented by calcium carbonate precipitated from waters circulating through the relatively coarse grained rock. One of the most important conclusions to be drawn from their occurrence is, as stated, that movements must have taken place, to cause the injection of the dykes, while the sandstones which are interbedded with the shales, and which doubtless furnished the material of the dykes, were still unconsolidated.

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[1] Diller, J. S., Sandstone dykes, Bull. Geol. Soc. Am., Vol. I, 1890, pp. 411-442.

[2] Newson, J. F., Clastic dykes, Bull. Geol. Soc. Am., Vol. XIV, 1903, pp. 227-263

JOINTING. The jointing of the rocks of the Nanaimo series is usually irregular, although in a few places parallel sheet jointing was observed. Along the axes of the folds and in the weaker rocks the jointing is extreme, but in most places in the thick bedded sandstones and conglomerates the joints are few and small.

External.

RELATION TO OLDER FORMATIONS. The Nanaimo series rests unconformably upon the metamorphic sedimentary and volcanic rocks of the Vancouver group and the granitic rocks of upper Jurassic age that are intrusive into the metamorphic rocks. The surface upon which the Nanaimo series rest is one of considerable relief. Small irregularities are directly observable in exposed unconformities. These are best observed around the shores of the ridge of meta-volcanics north of Departure bay (see Plate V B). Here the basal conglomerate fills crevices, hollows, and small valleys in the meta-volcanics, while small ridges of the meta-volcanics not only surmount the basal conglomerate but the overlying calcareous sandstones or sandy calcarenites, which in several places rest directly upon the meta-volcanics. Also the contacts of the Nanaimo series with the underlying rocks, where not disturbed by intense folding and faulting, follow very closely the contours of present elevations, which must have been elevations at the time of deposition also, unless far more irregular and complex folding than is elsewhere observed is supposed.[1] It appears that the sediments were deposited in bays, while resistant rocks formed headlands, which now project in the basins underlain by the Nanaimo series. The Mt. Hayes ridge in the southern part of the Nanaimo map-area, which surmounts the Nanaimo basin by 500 to 1,000 feet, seems to have been such a headland, and it is probable that Mt. Benson was a similar but much larger headland. It is also found, considering the whole of the Nanaimo basin of which that portion in the Nanaimo map-area is only a small part, but apparently the deepest, that some of the basal sediments near the larger of the old headlands, like that comprising the most of Saltspring island, correspond with formations somewhat above the base of the deeper parts of the basin. It is probable that the conglomerate which rests directly upon the north flank of Mt. Benson west of the Nanaimo map-area corresponds to the Extension conglomerate. It has been seen that in places the Benson basal conglomerate thins out completely, the Haslam arkoses resting directly upon the crystalline rocks, and in the northern part of the Nanaimo map-area, near the ridge of Vancouver meta-volcanics north of Departure bay, all the lower members of the Nanaimo series become very much thinner and some of them apparently pinch out entirely. At the northwest angle of Departure bay an outcrop of Extension conglomerate occurs within a hundred feet of the Vancouver meta-volcanics. The two formations may be separated by a fault, but there is no direct evidence of one. Also Snake island, composed of the middle sandstones of the uppermost (Gabriola) formation of the Nanaimo series, which has an average thickness of 6,760 feet, is only 7,200 feet distant from Five Finger island, composed of the Vancouver meta-volcanics although the average dip of the rocks on Snake island is only 30 degrees. From all of this evidence, therefore, one feels confident in stating that the surface upon which the Nanaimo series rests is one of great variety and considerable relief, the differences in elevation possibly being as much as 2,000 feet.

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[1] See Memoir No. 13, Geol. Surv., Canada, 1912, pp. 132-133.

Near the underlying crystallines the Nanaimo series have been folded against them, so that the strikes of the lower beds of the Nanaimo series are parallel to the contacts and the dips are steep, usually away from the contact. Around the ridge north of Departure bay, the dips shallow very quickly, but near the east flank of Mt. Benson the Haslam shales are involved in several small folds. In the southwestern part of the map-area, the dips are steep, 80 degrees to 35 degrees, for about 1,000 feet away from the contact, along and near which some bedding faults have taken place.

RELATION TO YOUNGER FORMATIONS. The only younger rock, with the exception of the superficial deposits, that is in contact with the Nanaimo series, is the dacite porphyrite dyke, which cuts the Benson conglomerate exposed in the Haslam Creek canyon.

MODE OF ORIGIN.

The Nanaimo series, as shown by its fauna, is partly of marine origin, doubtless estuarine, since it was deposited on a surface of considerable relief, and under varying conditions, shown by the rapid vertical and lateral gradation of the sediments. The series also contains land plants and coal, most probably of fresh water accumulation. Hence conditions of fresh or at least brackish water, that is terrestrial conditions, alternated with marine conditions. The upper part of the Nanaimo series, the Gabriola formation, however, contains few or no marine organisms, the only fossils being a few obscure plants. Therefore, it is possible that the alternating conditions recorded in the lower part of the Nanaimo formation were finally replaced entirely by terrestrial conditions. The lithological character of the sediments, the sandstones being composed chiefly of angular to subangular fragments and of a large percentage of easily decomposed minerals, such as feldspar, indicates a very rapid accumulation and deposition in relatively small basins, where the detritus was not subject to severe wave action. In general the conglomerates are composed chiefly of quartz and quartzose rocks, the sandstones chiefly of granitic detritus, quartz, feldspar, and dark coloured accessories, and the shales chiefly of volcanic detritus. This rather peculiar feature suggests a simple yet fairly plausible explanation. Of all the underlying rocks whose detritus composes the sediments, the volcanic rocks alone were chemically disintegrated and their detritus being very fine grained was deposited as mud, which now forms the shales. The granitic rocks were mechanically disintegrated and broken down into a coarse feldspathic sand, furnishing the material for the sandstones. But the quartz veins and the quartzose rocks were broken down only into a coarse rubble, the material for the conglomerates.

AGE AND CORRELATION.

Based on the determination, by Whiteaves, of the fossils from the Nanaimo series, collected in great numbers, by Richardson and others, from the Nanaimo map-area, elsewhere on Vancouver island, and from the small islands off the east coast, the series has been correlated with the Chico (Upper Cretaceous) of the California Cretaceous and approximately with the Pierre of the Great Plains. Identical species have been collected throughout the series, from the Haslam shales to the upper shales of the Northumberland formation, the Gabriola formation as already stated being virtually unfossiliferous. Only a few fossils were collected by the writer and these have been determined by Mr. L. D. Burling, who lists them as follows:—

From the Haslam formation, north shore of Departure bay, one-fourth of a mile east of the biological station.

Gyrodes excavata (Michelin)?
Inoceramus sp.?
Ostrea sp.
Trigonia evansana (Meek).
Anomia?
Protocardium?
Meretrix nitida (Gabb).
Linearia sp.
Cymbophora ashburneri (Gabb)?

From the Haslam formation, Horswell bluffs, one mile east of biological station.

Trigonia evansana (Meek).
Lima multiradiata (Gabb).
Tellina quadrata (Gabb)?
Meretrix nitida (Gabb).
Cymbophora ashburneri (Gabb)?

From the Cedar District formation, Nanaimo river, one-fourth of a mile south of Stovely.

Pelecypod, may be Cytherea.

Tube-like bodies resembling worm borings.

Unidentified plant remains, a part of a leaf resembling Populus (according to Mr. W. J. Wilson).

All of the determined species have been previously found and described from the Nanaimo series of the Nanaimo map-area.

The Nanaimo series were deformed by forces acting from the northeast, probably having their origin below the downfold between Vancouver island and the mainland, since to the south of the Nanaimo map-area the anticlines have been overturned to the southwest. The deformation presumably took place at or near the close of the Eocene period, at the same time that upper Eocene, Metchosin volcanics of the southern part of Vancouver island[1] were deformed. There seems to have been no wide-spread deformation on the Pacific coast at the close of the Cretaceous, corresponding with the Laramide revolution of the interior, for as Arnold[2] points out, with one exception at San Diego, California, the unconformity between the Eocene and the Chico (equivalent to the Nanaimo) is not angular, but as far as the stratigraphic evidence goes, the two formations represent an apparently uninterrupted period of sedimentation. This conclusion has been confirmed in general by the writers' work of 1910 to 1912 on Vancouver island; for although there were local movements throughout the deposition of the Nanaimo sediments, and doubtless an uplift without much folding at the close of the Cretaceous, since definitely lower Eocene sediments are not known in the region, yet the first pronounced deformation after the late Jurassic or early Cretaceous took place after the close of Eocene sedimentation and volcanism.

DACITE PORPHYRITE.

Although dacite and trachyte porphyrite dykes and sills cutting the Nanaimo series are well known in other parts of Vancouver island, at Comox and Suquash,[3] only one small dyke of dacite porphyrite occurs cutting the Nanaimo series in the Nanaimo map-area. This dyke is exposed in the canyon of Haslam creek, near the southwest corner of the map-area, and cuts the Benson basal conglomerate, only 150 feet above the base of the entire series. It is 4 feet wide and strikes N. 60° W., dipping 65° N.E., and is almost parallel to the bedding, which is here N. 80°—90° W., dipping 50°—80° N.E.

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[1] See Memoir No. 36, Geol. Surv., Canada.

[2] Arnold, Ralph, Tertiary faunas of the Pacific Coast, Jour. of Geol. Vol. 17, 1909, p. 512.

[3] Sutton, W. J., Manchester Geol. and Min. Soc. Trans., Vol. XXVIII, pp. 307-314, 1904. Clapp, C. H., Summary Report, 1911, Geol. Survey, Canada, pp. 105–107.

The dyke rock is a yellowish brown aphanitic rock containing fragments of quartz, chert, and black slate, with disseminated pyrite, which is greatly altered to limonite, thus colouring the rock. Under the microscope the rock is seen to consist essentially of plagioclase feldspar, and quartz, with accessory magnetite and apatite. Both the feldspar and quartz form a few small phenocrysts 1 to 2 mm. in diameter. The groundmass is prevailingly feldspathic consisting of diversely arranged feldspar laths. The rock is very greatly altered, being largely replaced by calcite as well as cut by calcite veinlets. Other secondary minerals are sericite and kaolin as well as pyrite and limonite.

The dyke is apparently cross-cutting and contains fragments of the rocks and minerals of the conglomerate. Its age is doubtful, but it is certainly post-Cretaceous and doubtless should be correlated with the other dacite and trachyte porphyrites of Vancouver island that cut the Nanaimo series. These are generally considered, with little evidence, however, to be of Eocene age.

SUPERFICIAL DEPOSITS.

Most of the Nanaimo map-area is covered with drift of various kinds, which, although deposited by various agencies, is, for the larger part, primarily of glacial origin. The drift, with other features, such as glacial grooving and erosion, records two epochs of glacial occupation and two corresponding epochs of glacial retreat. These two epochs of glaciation have been previously noted[1] and have been called by Willis from his studies in Puget Sound region, the Admiralty and Vashon epochs, the interglacial epoch being called the Puyallup. Since there is little question that the glacial and interglacial epochs recorded in the superficial deposits of the Nanaimo map-area can be correlated with those of the Puget Sound region, the names proposed by Willis are used in this report, as they are in the writer's report on the Victoria and Saanich map-areas. Colwood, the name for one of the members of the superficial deposits of the Victoria map-area, is also used. Distinguishing the various post-Glacial as well as Glacial deposits we may subdivide the superficial deposits as follows:—

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[1] Dawson, G. M., Trans., Royal Soc. Can., Vol. VIII, 1890, Sec. 4, pp. 43-44.
Willis, Bailey, Drift phenomena in Puget Sound: Bull. Geol. Soc. Am., Vol. IX, 1898, pp. 112-162.
Willis, Bailey and Smith, O. G., Tacoma Folio No. 54, U.S. Geol. Surv., 1899.
LeRoy, O., Geol. Surv. Can., Pub. 996, 1908, p. 27.
Clapp, C. H., Memoir No. 36, Geol. Surv. Can, 1914, pp. 107-121

Post-Glacial epoch.
        Beach alluvium.
        Swamp, valley, and delta alluvium.
        Rock debris.
Vashon glacial epoch.
    Stage of glacial retreat.
        Colwood sands and gravels.
    Stage of glacial occupation.
        Vashon drift.
Puyallup interglacial epoch.
        Puyallup clays, sands, and gravels.
Admiralty glacial epoch.
        Admiralty till.

DISTRIBUTION AND CHARACTER OF DEPOSITS.

Admiralty Till.

The Admiralty till, which is the oldest of the superficial deposits of the region, is not clearly distinguished in the Nanaimo map-area. In a few places, however, the Puyallup deposits or the Vashon drift overlie an older till 3 or 4 feet thick, which probably represents the Admiralty till, but is not present in sufficient amount to be shown on the accompanying map of the superficial geology. It is probable, however, that some of the glacial drift in the higher western portion of the map-area, mapped as Vashon drift, is referable to the Admiralty epoch; but it can not be distinguished from the more abundant Vashon drift. What is supposed to be the Admiralty till is a yellowish grey, fine sandy and rudely stratified till, with numerous and irregularly distributed rounded pebbles or boulders up to 6 inches in diameter.

Puyallup Clays, Sands, and Gravels.

The Puyallup interglacial deposits consist of well stratified clays, sands, and gravels. In general the clays occur near the base of the deposits and the sands and gravels near the top. However, in mapping, it has not been possible to separate the clays from the sands and gravels, as has been done in the Victoria and Saanich map-areas.[1] With the exception of the southwestern portion, the Puyallup deposits are found throughout the Nanaimo map-area, usually at elevations of less than 300 or 400 feet, although to the southeast of Mt. Benson, stratified sandy clays, mapped with the Puyallup deposits, are found above 500 feet. The deposits are thickest and best developed to the west and northwest of the city of Nanaimo and in the valley extending from the mouth of the Nanaimo river to Ladysmith (Oyster) harbour, in which the lower part of the Nanaimo river flows. In the southwestern part of the map-area the deposits never existed, but on and near the larger ridges of the rest of the map-area and on the islands they have apparently been largely eroded during the Vashon glacial period, or else are covered with the Vashon drift. Even in those places where the deposits are best developed, they are covered by a thin but fairly persistent covering of Vashon drift, which is represented on the accompanying map, however, only where well developed. The country underlain by the Puyallup deposits is usually gently rolling or flat, although somewhat diversified by the valleys of small intermittent streams, and by terraces cut in the deposits along the lower part of the Nanaimo river. To the northwest of Nanaimo, the deposits form a rolling plain from 300 to 400 feet above sea-level, with a steep eastern slope to the shore, and in places, as along the southwest shore of Departure bay, with fairly steep cliffs 40 to 100 feet high. In places, the deposits have apparently been partly eroded by the Vashon glaciers, so that uneroded portions remain as sand and gravel ridges, half a mile to a mile long, an eighth to a fourth of a mile wide, and 60 to 100 feet high, with their long axes in the direction of glacial movement, about S. 50° E.

The clays are yellowish grey to bluish grey, sandy, and most of them of poor plasticity. They are interbedded with clayey sands and even coarse sands and gravels, which as mentioned, predominate in the upper portion of the Puyallup deposits. The sands and gravels are well stratified and occur in flat lying beds up to several feet in thickness, although the individual beds are more or less lens-shaped and overlap and replace one another. Many of the beds of sand are also cross stratified. Irregularly distributed throughout the deposits, but more conspicuous and apparently more numerous in the lower portion, are subangular to rounded, glacially scratched and polished pebbles and boulders, up to a foot or more in diameter, of the crystalline rocks of the region, chiefly of granodiorite. Some of the clays and clayey sands are carbonaceous and contain plant remains and impressions. The deposits contain marine organisms also, as do the Puyallup deposits of the Victoria and Saanich map-areas. In the Nanaimo map-area, however, the organisms are not numerous and none were found by the writer's party, but they have been found by Dawson[1] at an elevation of 70 feet above sea-level.

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[1] See Memoir No. 36, Geol. Surv., Canada, 1914, pp. 109-111.

The Puyallup deposit rests in a few places upon the Admiralty till, but much more frequently rests directly upon the glaciated surfaces of the underlying hard rocks. It varies greatly in thickness, largely according to the irregularities in the underlying hard rock surface. Over extensive areas, for example to the east of the lower part of the Nanaimo river, it is very thin, averaging only 3 or 4 feet, but northwest of Nanaimo it has a maximum thickness of at least 150 feet, and presumably nearly 250 feet. It is unconformably overlain by the Vashon drift, and is commonly strewn with large glacial erratic boulders.

Vashon Drift.

The Vashon drift covers the greater part of the Nanaimo map-area, mantling the interglacial deposits. However, below elevations of 300 or 400 feet, except near the ridges in the lower portions of the map-area, this mantle is thin, seldom more than 4 or 5 feet thick, and frequently thins out completely, so that over large areas it is absent or is represented only by the glacial erratic boulders which occur strewn over the surface of the interglacial deposits. As already mentioned, the drift is

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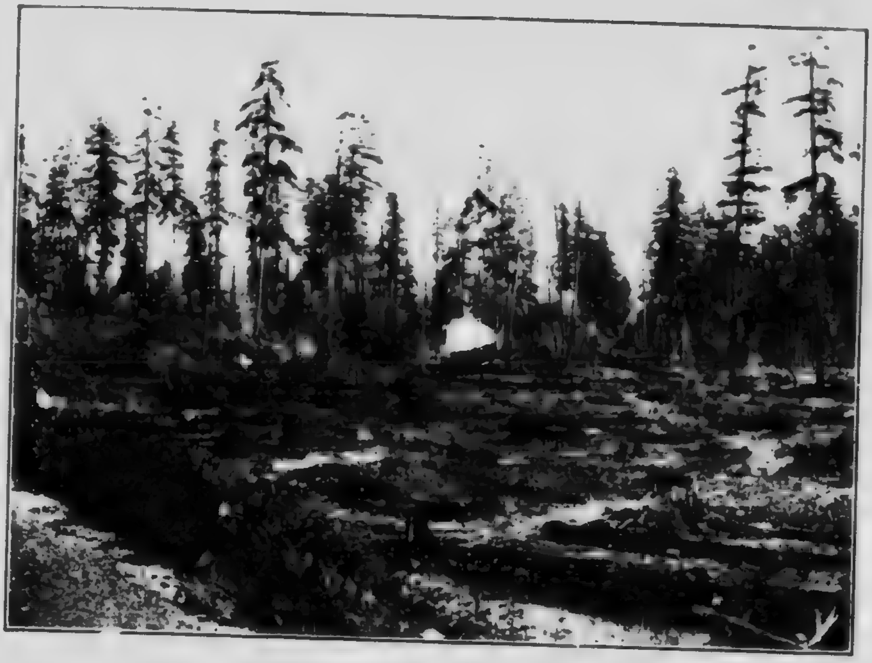
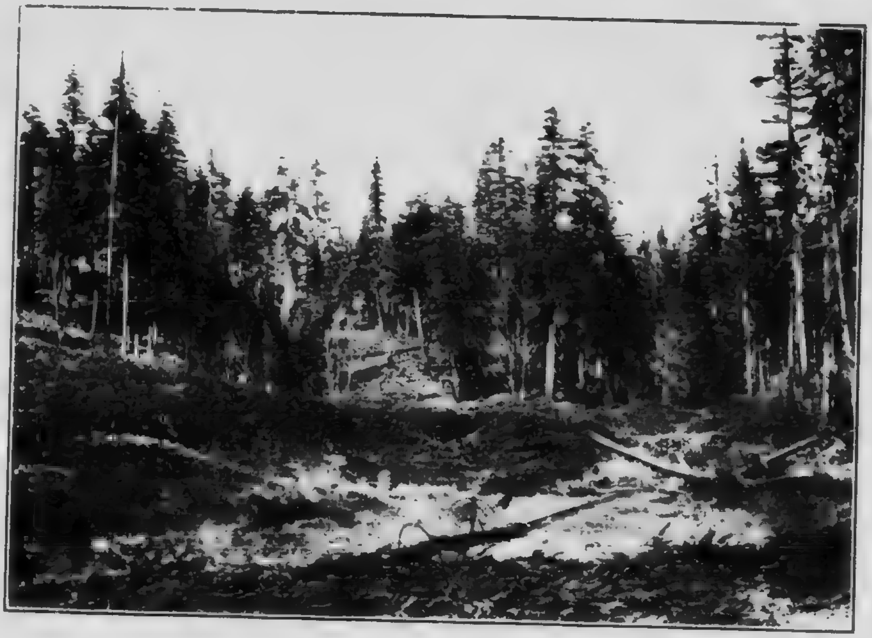
[1] Dawson, G. M., Quart. Jour. Geol. Soc., Vol. XXXVII, 1881, p. 179.

PLATE X.



A



B

A. A Nanaimo delta terrace, north of Nanaimo river near the Esquimalt and Nanaimo railway.

B. Kames and kettles near inner border of the Nan [illegible] between Nanaimo river and Haslam creek, west of Extension [illegible] railway.

shown on the accompanying map of the superficial geology only where it attains a significant thickness, materially changing the character of the topography, soil, and vegetation, and where it is consequently easily recognized. In the higher southwestern part of the map-area the larger part of the drift mantle is composed of Vashon drift. It is probable, however, that this drift is mixed with more or less of the Admiralty till from which it is indistinguishable. The Vashon drift seldom forms distinct and characteristic topographic features such as moraines and eskers, but merely forms a mantle covering either the hard rocks or the interglacial deposits. However, in the southwestern part of the map-area it forms small hummocky moraines and to the north of Mt. Hayes are three or four morainal hills, two of them in the lea of a large outcrop, elongate in the direction of glacial movement, about S. 65° E. The drift has, of course, filled up many of the smaller hollows and valleys in the surface upon which it lies, and its own surface is marked by small irregularities, such as low rounded hills and undrained shallow basins, many of which hold small lakes or have been filled with alluvium. The maximum exposed thickness of the drift is about 50 feet, but it doubtless attains a much greater thickness in places, and may exceed even 150 feet. Its average thickness where shown on the map, is probably about 15 to 25 feet.

The Vashon drift is chiefly an unsorted mixture of coarse yellow sand, gravel, and clay, with numerous subangular to rounded glaciated cobbles and boulders scattered irregularly through it. In places, the sand, which greatly predominates is rudely stratified. Near the surface the drift is usually oxidized to dark brown, and passes into a dark, sandy and gravelly loam which usually covers it.

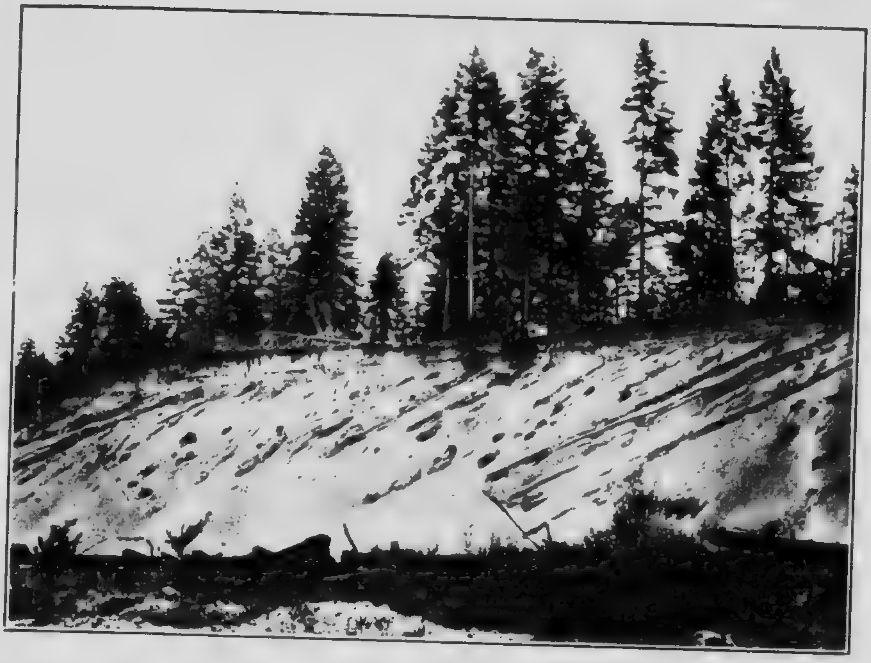
Colwood Sands and Gravels.

In the south central part of the map-area, bordering the Nanaimo river between the western boundary of the map-area and the Esquimalt and Nanaimo railway, and extending south to the southern boundary of the map-area, near Ladysmith, is a thick deposit of sand and gravel. The deposit forms a terraced plain, over 6 miles wide at its outer portion, narrowing to a few hundred feet 3 miles up the Nanaimo river (see Plate XA).

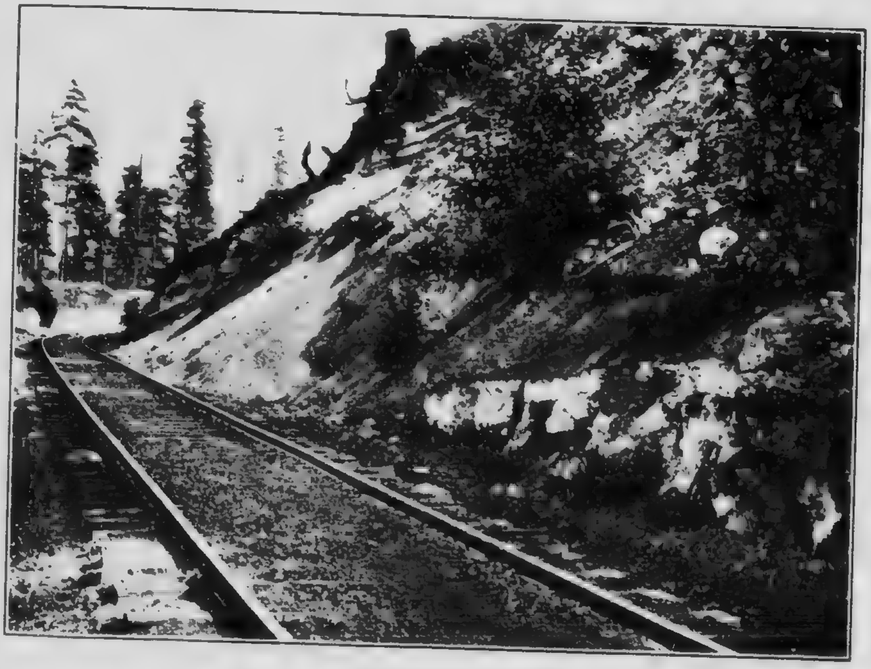
For another 3 miles the sand and gravel merely form terraces bordering the river. Along the western border of the broad portion of the deposit, the terraced plain attains an elevation of 400 feet above sea-level. From this elevation, it descends to the eastward nearly to sea-level, and even to sea-level in its southern portion, in a series of broad terraces, varying in height from 10 to 50 feet. Near the western inner border of the broad portion of the plain and south of the Nanaimo river, are many well developed kames and kettle or ice block holes (see Plate XB). The largest kettle holes, which are shown on the topographic map, are 100 to 800 feet across and 10 to 80 feet deep.

The deposit consists chiefly of yellow, coarse sands and fairly well rounded gravels, composed largely of pebbles of the undecomposed granitic rocks. There are a few beds of yellow to bluish grey, sandy clay interstratified with the sands and gravels, but the clays are rarely smooth or plastic. The upper or surface portion of the terraces is usually composed of horizontally stratified coarse gravels and is even strewn with a few boulders 2 to 3 feet in diameter. These coarse gravels, which vary in thickness from 5 to 15 feet, overlie the finer grained beds of coarse sand and fine gravel which are usually steeply cross-bedded, with dips of 15 to 30 degrees to the eastward. Thus, a section of almost any terrace shows what is apparently a typical delta structure, with coarse, horizontally bedded top-set beds overlying finer, steeply bedded fore-set beds (see Plate XIA). However, this apparent or pseudo delta structure is probably the result of the truncation of steeply stratified sands and gravels, which compose the larger part of the deposit, by the river which terraced the deposit and which deposited its own load on top of the truncated beds as horizontally bedded coarse gravels.

The Colwood sands and gravels overlie the interglacial deposits and presumably overlie the Vashon drift since the surface of the Vashon drift is seen dipping below the flat surfaces of the Colwood sands and gravels, and since in other parts of Vancouver island the Colwood sands and gravels are seen directly overlying the Vashon drift. Except in the kettle holes and a few other shallow basins, the Colwood sands and gravels are not covered by any younger deposit and even the soil



A



B

A. Sand and gravel pit, Extension collieries railway, south of Nanaimo river; showing Colwood sands and gravels of the Nanaimo delta, with a pseudo delta structure produced by the truncation of the steeply dipping fore-set beds and contemporaneous deposition of the horizontally bedded, coarse, river gravels.

B. Section of a terrace of the Nanaimo delta, Extension collieries railway, south of Nanaimo river; showing Colwood sands and gravels protected from further erosion by the underlying Extension conglomerate.

covering is thin. The thickness of the sands and gravels is at least 100 feet, and their maximum thickness may be as great as 200 or 250 feet.

Rock Debris.

Covering the hard rocks of Gabriola, Newcastle, and Protection islands, is a thin mantle consisting largely of small to large angular fragments of the immediately underlying rocks, chiefly Gabriola and Protection sandstones, mixed with more or less glacial till and,in some places, even with the interglacial deposits. This mantle of rock debris, which is mapped as such, appears to be the result of the breaking down by mechanical agencies in post-Glacial time, of the underlying sandstones. Similar debris has been found at the base of some of the sandstone cliffs of Vancouver island, and a coarse talus of granodiorite and diorite has been formed at the base of the steep northeast face of Mt. Hayes. Where these talus deposits are extensive they are shown on the accompanying map as rock debris.

Swamp, Valley, and Delta Alluvium.

In the undrained hollows of the drift mantle, and along sluggishly drained valleys in the drift mantle or in valleys in the hard rocks, especially the northwest-southeast valleys which have been widened and deepened by glacial scour and partially filled and dammed by drift deposits, are deposits of black carbonaceous mud or muck and of fine grained siliceous clays or silts. These were doubtless deposited during post-Glacial or Recent time in sluggish streams or in the standing water of small lakes or ponds, some of which are only partially filled and are now swamps, while others are completely filled or have been drained artificially. Also, at the mouth of the Nanaimo river a large delta of similar material is rapidly filling the drowned valley between Nanaimo and Jack point (see Plate II). A similar but much smaller delta is being formed at the head of Ladysmith (Oyster) harbour.

Beach Alluvium.

As described under shore-lines, part of the sand and gravel of the drift deposits that have been retrograded during the present marine cycle, now forms small narrow beaches between rock headlands; and in a few places, small barrier beaches and sand bars, which are shown on the accompanying map, have been formed.

STRUCTURE.

The sequence of the various superficial deposits as well as their general structure has already been given, but the structure may be summarized here. All of the deposits are essentially flat lying. Four marked unconformities occur in the superficial deposits—between the Admiralty till and the Puyallup interglacial deposits or the Vashon drift; between the Puyallup deposits and the Vashon drift; between the Puyallup deposits or the Vashon drift and the Colwood sands and gravels; and between the Glacial deposits and the post-Glacial alluvium. Besides these there are numberless local unconformities caused by cross stratification and contemporaneous erosion and deposition.

GLACIOLOGY AND MODE OF ORIGIN OF SUPERFICIAL DEPOSITS.

From the character of the superficial deposits it is seen that they are composed largely of glacial debris and detritus, so that a discussion of their origin is so closely linked with a discussion of the glaciation of the Nanaimo map-area that the two topics are treated together. From the wide-spread distribution of glacial till on the upland of Vancouver island, and from the severe glaciation of the upland, mountains nearly 5,000 feet high having been rounded, it is seen that Vancouver island was at some time during the Glacial period nearly smothered by a thick ice-cap. Valley glaciers filled the larger valleys, and those flowing eastward from the east slope of the Vancouver range joined with the larger and more numerous glaciers flowing westward from the ranges of the mainland, and formed an extensive piedmont glacier which occupied the downfold between the Vancouver range and the ranges of the mainland. The southward or southeastward flowing portion of this piedmont glacier, called by Dawson[1] the Strait of Georgia glacier, overrode the eastern lowland portion of the Nanaimo map-area, removed virtually all of the surface soil, and smoothed off the angularities of the pre-Glacial rock surface.

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[1] Dawson, G. M., Trans. Royal Soc. Can., Vol. VIII, 1890, sec. 4, p. 29.

The rocks of the Nanaimo map-area were not only smoothed but grooved and striated, and the smaller ledges were worn into 'boat-bottomed' shapes or roches moutonnées, with their long axes in the direction of glacial movement, their smaller, bow or stoss ends being pointed in the direction from which the glaciers came. The minor features of glacial scour are not well preserved in the rocks of the Nanaimo series, except where the rocks have been protected from erosion and disintegration by a drift cover. These features are best observed where these protected rocks have been very recently uncovered. The abrasion caused by the glacier or glaciers, since it is probable that valley glaciers flowing eastward from the Vancouver Island ice-cap mingled in the higher western part of the map-area with the Strait of Georgia glacier, was not extreme. In most places, the glaciers merely rounded the sedimentary rock ridges, and rounded the crystalline rock ledges into knob-like forms. In a few places, however, the glaciation was more intense and whole valley slopes were smoothed, the valley floors deepened, especially in places, and the minor irregularities due to normal erosion completely abraded. Examples of this type of glacial erosion are afforded by Northumberland channel and Ladysmith (Oyster) harbour, and on the east flank of Mt. Benson two small lakes, their size now increased by artificial dams, occur in a locally deepened valley. The east-west ridge of crystalline rocks north of Departure bay, well depicted on the topographic map, is interesting in that it shows the two types of glaciation, the submature and the mature. The north slope of the ridge is steep but nearly smooth, the lower portion being largely drift covered, while the southern slope is characterized by a great many small rounded hills 50 to over 100 feet high. The more mature glaciation of the northern slope was probably due to a glacier flowing eastward from the Vancouver range through the Nanoose Harbour valley.

The general direction of the movement of the Strait of Georgia glacier over the lowland of the Nanaimo map-area was nearly S. 55° W., parallel to the downfold between the Vancouver range and the ranges of the mainland. In the eastern part of the lowland, bordering the downfold, there appears to have been little deviation of the glacial movement from this general direction. But in the higher portions of the western part of the map-area, especially near the east-west ridges composed of crystalline rock in the northern and southern parts of the map-area, the topography and the eastward movement of the glaciers descending from the Vancouver range greatly affected the glacial movement, which is there more nearly east and west, averaging about S. 70° E.

The only deposit of the Nanaimo map-area that was clearly deposited during this period of glaciation is the Admiralty till. It was doubtless more extensive than appears at present, and probably furnished much of the material of the Puyallup interglacial deposits, and, as mentioned, doubtless occurs in the higher western portions of the map-area mingled with the Vashon drift. It was deposited directly by ice, but part of it was apparently deposited in water, probably below sea-level, since it is partly stratified and directly overlain by the marine interglacial deposits.

On the retreat of the glaciers of the Admiralty epoch, the land stood at least 70 feet lower than it is at present, and presumably nearly 100 feet lower, as is shown by the occurrence of marine fossils in the interglacial deposits up to an elevation of 70 feet and the occurrence of deposits similar to those containing the fossils up to elevations of 300 to 400 feet. Hence the pre-Glacial lowland must have been submerged below sea-level, forming estuaries. In these estuaries, under conditions of comparative quiet and of moderate temperature, shown by the remains of vegetable and animal life, the lower portion of the Puyallup deposits was deposited. The glaciers had not, however, completely disappeared from the region, as the irregularly distributed pebbles and large erratic boulders found in the Puyallup deposits were doubtless dropped from floating ice. During the later stages of the interglacial epoch, when the upper sands and gravels were deposited, either shallower water prevailed or else the rivers and streams issuing from the glacial front, perhaps advancing at this time, were more heavily loaded with coarser detritus.

The interglacial epoch was brought to a close by the second glacial advance, the Vashon glacial epoch. At this time the Vashon drift was deposited, largely by ice alone, but since some of it is rudely stratified it was doubtless in part deposited by water, either by streams flowing beneath the glacier or issuing at its front. The Vashon glaciation was less intense than the Admiralty glaciation, the Vashon glaciers merely eroding portions of the older unconsolidated glacial deposits.

To judge from the absence of conspicuous moraines composed of the Vashon drift, the retreat of the Vashon glaciers must have been fairly rapid.[1] Nevertheless, the Colwood sands and gravels were deposited apparently by heavily loaded streams issuing from valley glaciers occupying the Nanaimo River and Haslam Creek valleys. The deposit is, therefore, a delta as is further indicated by its steep stratification, and is called the Nanaimo delta. That the delta was formed near the front of the ice during glacial recession is fully substantiated by the presence of kettle holes and kames near its border. It is possible that the Nanaimo delta was deposited in a lake ponded by the Strait of Georgia glacier, since it appears that the glacier covered the islands during the deposition of the delta deposits as the islands are merely covered by rock debris. But since it is positively known by the occurrence of marinefossils at elevations about 400 feet in deposits overlying the Vashon drift in the vicinity, on Texada island and near Vancouver,[2] that a recent uplift of 400 feet has occurred, and since that is the elevation of the Nanaimo delta, it is most probable that the delta was deposited in salt water. Since the uplift, the delta has been terraced by the revived streams crossing it.

The origin of the post-Glacial deposits has been already sufficiently indicated.

AGE AND CORRELATION.

There is, of course, little question as to the general age of the superficial deposits. The Admiralty till and Vashon drift were clearly deposited during two epochs of glaciation separated by the Puyallup interglacial epoch, during which the Puyallup clays, sands, and gravels, in part of marine origins, were deposited. In these interglacial deposits are found the following Pleistocene fossils, also found in the interglacial deposits of the Victoria and Saanich map-areas.[1]

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[1] Cf. Dawson, G. M., Royal Soc. Can., Vol. VIII, 1890, sec. 4, p. 45.

[2] Personal communication by R. G. McConnell and Charles Camsell.

Saxicava rugosa.
Mya truncata.
Leda fossa.

The sands and gravels of the Nanaimo delta were clearly deposited during the recession of the Vashon glaciers, presumably during the transition between Pleistocene and Recent times, and hence are correlated with the Colwood sands and gravels of the Victoria map-area.[2] In Recent time, the swamp, valley and delta and beach alluvium has been deposited, and the bared glaciated rocks have been disintegrated into rock debris.

As has already been stated the two glacial epochs of the Nanaimo map-area are correlated with the two glacial epochs which have been recognized in other parts of the North Pacific coast and called the Admiralty and Vashon epochs. The features of the superficial deposits of the Nanaimo map-area agree very closely with those of the Victoria and Saanich map-area,[3] which are correlated with much certainty with those of the Tacoma quadrangle[4] (map-area). The Vashon epoch[5] has been correlated with the last epoch of glaciation of the central and eastern parts of North America, the Wisconsin. In the Puget Sound region, the Admiralty till and Puyallup interglacial deposits are frequently weathered, suggesting that they were long exposed before the Vashon glaciation. But in the Nanaimo map-area, as in the Victoria and Saanich map-areas, the till and interglacial deposits are unweathered. However, there must have been a long interval between the Vashon and Admiralty epochs, but the Admiralty epoch cannot at present be correlated with any certainty with one of the pre-Wisconsin glacial epochs of central and eastern North America.

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[1] Dawson, G. M., Quart. Jour. Geol. Soc., Vol. XXXVII, 1881, p. 279.
[2] Memoir No. 36, Geol. Surv., Canada; 1914, p. 112.
[3] See Memoir No. 36, Geol. Surv., Canada; 1914, pp. 107-121.
[4] Willis, B., and Smith, O. G., Tacoma, folio No. 54, U.S. Geol. Surv., 1899.
[5] Dawson, G. M., Roy. Soc. Can., Vol. VIII, 1890, sec. 4, p. 54.
Bretz, Harlor, J., Terminal Moraine of the Puget Sound glacior: Jour. of Geol. Vol. XIX, 1911, p. 174.

HISTORICAL GEOLOGY.

During lower Mesozoic (Triassic and Jurassic) time in southern Vancouver island extensive volcanism took place, presumably under submarine conditions, at which time the moderately basic Vancouver volcanics were erupted. At some time during the accumulation of the volcanic rocks a change of conditions brought about the deposition of fine grained sediments, thus forming the rocks of the Sicker series. At or near the close of the lower Mesozoic, the volcanic and sedimentary rocks, which compose the Vancouver group, were greatly deformed, the main axis of deformation corresponding with the trend of the island. During and closely following the deformation, batholiths and stocks of granitic rocks were intruded into the folded rocks of the Vancouver group, greatly metamorphosing them. The principal intrusive was the Saanich granodiorite, which was intrusive also into a gabbro-diorite, which appears to have been an early peripheral differentiate of the Saanich granodiorite magma. During the same general period, but whether before or after the intrusion of the Saanich granodiorite is not known, the Sicker series were injected by the Sicker gabbro porphyrite.

The granitic rocks were subsequently exposed by erosion presumably during the cycle initiated by the deformation, and upon an erosion surface of moderate relief composed of the granitic rocks and of the rocks of the Vancouver group, a series of fragmental sediments, the Nanaimo series, was deposited in Upper Cretaceous time. The sediments were derived chiefly from the underlying granitic and metamorphic rocks and were deposited in a marine basin between Vancouver island and the mainland, which basin was probably the result of deformation and was depressed at least as early as the upper Jurassic folding. The deposition took place under varying conditions, and it is probable that marine (estuarine) conditions alternated with those of fresh and brackish water. At the close of their deposition the sediments in the vicinity of the Nanaimo map-area averaged about 6,760 feet in thickness, while a few miles to the southeast they were about 10,000 feet thick. At that time it is probable that they covered the entire map-area, even the larger of the higher residuals of the irregular surface upon which they were deposited.

During the deposition of the Nanaimo series, local movements occurred, and at the close of sedimentation, near the beginning of Eocene time, the series was presumably uplifted without much folding. Farther south extensive volcanism and sedimentation took place during upper Eocene time, and at or near the close of the Eocene, the Eocene volcanics and sediments and the Nanaimo series were extensively folded and faulted, the main axis of deformation being about N. 70° W. It is probable that the forces causing the deformation acted from the northeast, doubtless having their origin below the basin between Vancouver island and the mainland, that was partially filled by the Upper Cretaceous and Eocene sedimentation.

This post-Eocene deformation initiated a new erosion cycle, which has been called the Tertiary cycle, although most of the erosion was probably accomplished during the Miocene period. During the Tertiary cycle all of the rocks of the map-area were greatly reduced. The Tertiary cycle was closed and a new cycle, the pre-Glacial cycle, was initiated by an uplift, that probably took place during Pliocene or possibly early Pleistocene[1] time. During the pre-Glacial cycle the uplifted surface, developed during the Tertiary cycle, was entirely destroyed and the region reduced to a lowland. The sedimentary rock cover was stripped from the higher portions of the crystalline rocks, re-exposing the old residuals of the pre-Upper Cretaceous erosion surface, which now form low ridges extending eastward from the upland to the west of the map-area, the ridges and upland steeply surmounting the sedimentary rock lowland. The sedimentary rocks were not reduced to a level, but the hard rocks remained as cuestas up to 700 feet high and 3 or 4 miles in length surmounting subsequent valleys cut in the soft rocks.

The pre-Glacial cycle was brought to a close by the advent of the Glacial period during which the Nanaimo map-area was twice overridden by glaciers. During the first epoch of glaciation, called the Admiralty, the southward flowing Strait of Georgia glacier mingled with the glaciers flowing eastward from the upland of Vancouver island, and overrode the Nanaimo map-area submaturely to maturely glaciating it. Either before the advent or directly following the retreat of the earlier and larger glaciers, the region was depressed, part of it below sea-level, apparently the eastern portion being depressed most. Hence, during the Puyallup interglacial epoch the pre-Glacial lowland was covered by marine and delta deposits composed largely of glacial detritus. During the later and less intense epoch of glaciation, the Vashon, the interglacial deposits were partially eroded by the smaller glaciers, which upon their apparently rapid retreat left the deposits partly covered by a younger drift, and by a large delta deposit, composed of Colwood sands and gravels, the Nanaimo delta, which formed at the front of two retreating glaciers occupying valleys flowing east from the upland.

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[1] Since sedimentation ceased abruptly at the close of the Miocene in this general region, the writer is inclined to believe that the uplift took place in early Pliocene times, compare Ralph Arnold, Journ. of Geol., Vol. 17, 1909, pp. 528-531; but other geologists, from results obtained inland, are inclined to place the uplift in late Pliocene or early Pleistocene times.

Doubtless soon after the retreat of the later glaciers the present cycle was initiated by an uplift of some 400 feet. This uplift brought the Glacial deposits above sea-level and they have been terraced by the larger transverse streams revived by the uplift. The revived streams have also cut narrow canyons in the underlying sedimentary rocks. The uplift was not sufficient to offset, in the eastern part of the map-area, the earlier depression, so that the subsequent valleys are there still below sea-level, while the hard rock ridges form islands and points. During the present marine cycle the uplifted Glacial deposits have been retrograded in places to form steep cliffs, but in most places the shore-lines in the hard rocks present the initial irregularities of the drowned surface.

CHAPTER V.

ECONOMIC GEOLOGY.

The mineral resources of the Nanaimo map-area consist chiefly of its coal deposits, which have been mined since 1852. Since then the industry has shown a steady increase and it has a very promising future. The other mineral resources include building stone, sand and gravel, and shale and surface clay. Other deposits which have been prospected are the impure limestones (calcarenites) at Departure bay and the mineralized shear zones and veins in the crystalline rocks.

COAL.

GENERAL DESCRIPTION.

The Nanaimo coal field occurs at the northwestern end of the Nanaimo basin, and with the exception of a small portion in the vicinity of Wellington, lies within the Nanaimo map-area; and the map-area embraces all of the mines producing at the present time. The productive area is only about 65 square miles, but the area virtually known to be underlain by workable coal seams is somewhat larger. The coal occurs chiefly in the lower part of the Nanaimo series in three seams, the Wellington, the Newcastle, and the Douglas. The lowest seam, the Wellington, lies at the base of the Extension formation and rests on the East Wellington sandstone, and is about 700 feet above the base of the Nanaimo series. The Newcastle seam occurs at the base of the Newcastle formation, and overlies the Wellington seam by about 800 to 1,000 feet. The Douglas seam is contained in the Newcastle formation, from 25 to 100 feet above the Newcastle seam. As already described,[1] the associated measures are moderately disturbed and have a general monoclinal structure with a low dip to the northeast. There are a few rather larger open folds and many smaller ones. There are also many minor faults and in the southwestern part of the field, affecting the Wellington seam only, are at least two and possibly four, reversed, strike faults with throws of 300 to 500 feet.

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[1] Structural Geology of the Nanaimo series.

The three seams are remarkably persistent considering the great variability of the associated rocks, but vary greatly in thickness and quality. In places a variation as great as from 2 or 3 feet of dirty slickensided coal or "rash" to 30 feet of clean coal occurs within a lateral distance of 100 feet. It seems as if this extreme variation is due to a folding of dirty or silty coal seams, when at least the clean coal was in a plastic or pasty condition, permitting it to flow away from the bends where an increased vertical pressure was developed, to the limbs of the folds where there was a corresponding decrease of pressure. There are also large, barren places in the seams owing to silting or similar causes. The coal seams are displaced also by small faults, although an actual break seldom occurs, the coal having been forced along the plane or zone of dislocation. Rarely the seams fold or wrinkle without any appreciable variation in thickness.

The coals of the various seams are, as a whole, much alike, and are high volatile bituminous coals of fair quality. The amount of fixed carbon in the best quality ranges from 45 to 60 per cent and the ash from 5 to 10 per cent. The coals, especially that from the Wellington seam, coke readily. The following are the available analyses of coals from the Nanaimo field.

Analyses of Coals from the Nanaimo Field.

	WELLINGTON.			NEW-CASTLE.	DOUGLAS.	
Proximate analysis	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Moisture........	1·65	1·16	1·1	1·9	1·6	1·54
Volatile combustible............	43·25	40·47	39·3	39·4	39·7	33·30
Fixed carbon.......	45·52	50·04	49·2	45·7	47·7	56·23
Ash...............	9·24	7·80	10·0	11·7	10·1	8·44
Sulphur............	1·24	0·53	0·4	1·3	0·9	0·49
	100·00	100·00	100·0	100·0	100·0	100 00

Analyses of Coals from the Nanaimo Field—Con.

	WELLINGTON.			NEWCASTLE.	DOUGLAS.	
Proximate analysis	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Coke	55·38	58·11	67·5	57·4	57·8	64·91
Its character	Firm, coherent.	Firm, coherent.	Good commercial.	Non-commercial agglomerate.	Poor commercial to non-commercial agglomerate.	Firm, coherent.
Fuel ratio	1·05	1·23	1·25	1·16	1·20	1·69
Ultimate analysis.						
Carbon	72·80	75·53	72·1	67·7	71·0	74·46
Hydrogen	5·17	5·13	4·7	4·7	4·9	5·42
Nitrogen	0·88	1·19	1·2	1·2	1·2	1·37
Oxygen	10·67	9·82	11·6	13·4	11·9	9·82
Sulphur	1·24	0·53	0·4	1·3	0·9	0·49
Ash	9·24	7·80	10·0	11·7	10·1	8·44
	100·00	100·00	100·0	100·0	100·0	100·0
Carbon hydrogen ratio	14·1	14·7	15·3	14·5	14·5	13·7
Calories (by determination with dry coal)	....	....	7310	6930	7130	....
B. T. U. (by determination with dry coal)	....	....	13160	12470	12830	....
Calories, by calculation from ultimate analysis	7 30	7450	6980	6530	6930	7470

No. 1. "Run of mine", East Wellington No. 1 mine, Vancouver-Nanaimo Coal Mining Co., C. H. Clapp, collector, F. G. Wait, analyst.

No. 2. "Run of mine", Nos. 1, 2, and 3 Extension mines, Canadian Collieries Co., C. H. Clapp, collector, F. G. Wait, analyst.

No. 3. Regular sample of commercial coal, 1½" screen and picking belt. Extension mine, Wellington Collieries Company (Canadian Collieries Company) Edgar Stansfield, Dept. of Mines, Mines Branch, Coals of Canada, Vol. II, Table LXVIII, Recalculated to an air-dry basis.

No. 4. Regular sample of commercial coal, over 2" screen and picking belt, No. 1 mine, Western Fuel Co., No. 1 North level, lower seam. Edgar Stansfield, Dept. of Mines, Mines Branch, Coals of Canada, Vol. II, Table LXVIII, Recalculated to an air-dry basis.

No. 5. Regular sample of commercial coal, over 2" screen and picking belt. No. 1 mine, Western Fuel Co., Upper seam or south side coal. Edgar Stansfield, Dept. of Mines, Mines Branch, Coals of Canada, Vol. II. Table LXVIII, Recalculated to an air-dry basis

No. 6. "Run of mine", South Wellington mine, Pacific Coast Coal Mines. C. H. Clapp, collector, F. G. Wait, analyst.

The following proximate analyses are from Dowling's compilation of analyses in Publication No. 1035, Geological Survey, Canada, 1909.

Proximate Analyses of Coals from the Nanaimo Field.

	Moisture.	Volatile combustible matter.	Fixed carbon	Ash.	Sulphur.	Fuel ratio	Calorific value B.T.U.
Wellington coal.							
(1) Wellington mine. . .	2·75	38·03	52·64	6·58	...	1·38	12567
(2) Wellington mine. .	8·57	25·30	56 40	9·52	0·21	2·22	
(3) Wellington mine	4·14	36·85	46·16	12·85	0·56	1·25	...
(4) Harewood mine .	1·58	33·84	52·17	11·85	0·56	1·53	12238
(4) Extension collieries	1·44	31·40	46·18	20·65	0·33	1·47	11401
(4) Extension collieries	1·52	35·27	57·04	5·85	0·32	1·61	13416
(4) Extension collieries	1·21	36·49	53·72	8·20	0·35	1·47	13261
(4) Extension collieries	1·2[illegible]	35·26	55 83	7·30	0·33	1·58	13199
Newcastle coal.							
(4) Nanaimo colliery No 1 shaft..................	2·86	35·84	54·79	5·5	1·01	1·53	12951
Douglas coal.							
(1) Newcastle island.	1·57	38·14	50·84	8·63	0 82	1·33	
(4) Nanaimo colliery No. 1 shaft....	1·88	33·27	54·67	9·40	0·70	1·64	12672
(4) Southfield colliery No. 5 shaft.......... ...	2·08	35·78	56·26	5·60	0·28	1·57	13261
(3) Southfield colliery No. 5 shaft................	2·06	34·07	56·94	6·67	0·25	1 67	...

References:—

(1) Reports of Geological Survey of Canada to Vol. XVI.

(2) Report on the efficiency of various coals used by the United States ships, 1893-95, Bureau of Equipment, Washington, 1895.

(3) Report on the efficiency of various coals used by the United States ships, 1896-98, Bureau of Equipment, Washington, 1899.

(4) Reports of Minister of Mines, B.C., 1902.

A small seam averaging about 2 feet thick, called the Little Wellington, overlies the Wellington locally in the extreme northwestern part of the basin, at a distance of 20 to 60 feet. It was mined at the Old Wellington collieries, within the Nanaimo map-area, at the old No. 1 shaft, and it is reported to have been mined at the old East Wellington colliery, also within the Nanaimo map-area. Another small seam occurs 80 to 100 feet above the Wellington seam near the Nanaimo river south of

Extension. The seam as exposed at "Jacks" prospect on the north bank of the Nanaimo river, three-fourths of a mile above the Extension collieries railway bridge, is about 10 feet thick and consists of a carbonaceous shale with lentils of bony coal, and occurs as an interbed in the Extension conglomerates and sandstones. A thousand feet to the east, apparently the same seam is exposed, and consists of 3 feet of bony coal with partings of sandstone and conglomerate. There appears to be still another small seam with a maximum thickness of 2 or 3 feet, in the Extension formation, from 200 to 250 feet above the Wellington seam. This has been found in several boreholes in the vicinity of Extension, and less than half a mile to the northeast of Extension, near the old railway grade, is a small prospect on what is apparently the outcrop of this seam. There it consists merely of carbonaceous shale with coaly lentils.

Besides the small seams in the Extension formation there are numerous lenses or lentils of coal in the Protection, Cedar District, and DeCourcy formations. Most of the lentils are only a few inches thick, but a few are 2 to 4 feet thick. Several of them have been prospected, but none of them, however, so far as known, are more than a few feet in lateral extent, or are of any commercial value.

The Wellington seam has been mined at Wellington, Northfield, East Wellington, Harewood Plains, and Extension, and is at present mined by the Vancouver-Nanaimo Coal Mining Company at East Wellington and by the Canadian Collieries (Dunsmuir) Company near Extension. The Newcastle and Douglas seams are usually worked together and have been mined extensively in the vicinity of Nanaimo. The mines there are operated by the Western Fuel Company. There has also been a large production from the Douglas seam south of Nanaimo, notably at Chase River, Southfield, and South Wellington. There is only one mine producing at present in this district, namely the South Wellington colliery operated by the Pacific Coast Collieries. Very recently the Douglas seam has been reached by two new shaft mines—by the Reserve mine of the Western Fuel Company on the Indian Reservation near the mouth of the Nanaimo river, at 1,064 feet, and by the Morden mine of the Pacific Coast Collieries between South Wellington and the Nanaimo river, at 610 feet.

Coal was first produced from the Nanaimo coal field in 1852, the production before the close of 1853 amounting to 2,000 tons. Since that time the production has shown a continuous although fluctuating increase. In 1875, the annual production first passed the 100,000 long tons mark, and in 1900 a production of over 1,000,000 tons a year was reached. The maximum production was attained in 1911 when it amounted to 1,184,719 long tons valued at over $4,000,000. This amounts to more than one-third of the entire production of British Columbia, which during the last few years has averaged over 3,000,000 long tons a year, although during 1911 it was considerably less owing to labour troubles in the East Kootenay district. The total production of the field to December 31, 1912, is approximately 24,500,000 long tons, about three-fifths of the total coal production of British Columbia.

The future of the coal industry is very promising, although thinner and deeper coals will have to be mined in the near future. As already stated, two new shaft mines have reached the Douglas seam in depth. Owing to the great variability of the seams and to the lack of public information, no figures can be given for the actual coal reserve at Nanaimo. But granting a moderate extension in depth and area, the probable reserve of the Nanaimo field, including the seams of 1 foot or over to a depth of 4,000 feet, is conservatively estimated as 1,340,000,000 l [illegible] ons. This estimate is based on the assumption of 3 seam [illegible] total average thickness of 10 feet, and a total area, large [illegible] in the Nanaimo map-area, of 181 square miles, none of the seams, however, extending over the entire area, and of 1,000,000 tons per square mile-foot.

WELLINGTON COAL SEAM.

Distribution and Thickness.

The Wellington s [illegible] which as stated rests on the East Wellington sandstone and the Extension formation, outcrops along the western border of the map-area. It is well developed in the northern part of the map-area in the vicinity of East Wellington where the seam averages 3 to 6 feet in thickness and consists almost entirely of clean coal, there being no persistent partings. The outcrop can be seen in the northern area at only one place, at the old Jingle Pot slope to the northwest of the New East Wellington colliery. The outcrop bends around the east flank of Mt. Benson, although the position of the outcrop and the character of the seam are unknown in this vicinity. Farther south the outcrop is well located at Harewood plains where there are three or four old slopes on the seam. In this locality the seam, although attaining a thickness of 10 feet, contains many thick partings of carbonaceous or coaly shale and the amount of clean coal in places is less than a foot. The seam outcrops along both sides of the Extension valley in the limbs of the Extension anticline, and the seam pitches below the Extension conglomerates, at the southeast end of the anticline nearly 1½ miles south of Nanaimo river. The seam is exposed at a few places along both sides of the anticlinal valley. It averages in thickness along the Extension valley from 6 to 10 feet, but in many places, especially in the northeastern limb of the anticline, it contains thick partings of carbonaceous shale and bony coal. The southwest limb of the anticline is broken by two reversed strike faults with throws of 500 and 150 feet respectively. The seam for nearly 4 miles outcrops a few yards to the southwest of the northeastern and larger fault, in the upthrown side. Farther southwest, the seam outcrops in the northeastward dipping limb of the shallow syncline southwest of the faults. The seam is not actually exposed until it crosses the Nanaimo river, but its position has been fairly well determined by underground mining. At Nanaimo river, south of Berkley creek, about 4 feet of clean coal is exposed for a distance of 25 yards. The seam also outcrops along the Nanaimo river in the limbs of the sharp anticline southeast of the Extension anticline. On the outcrop of the southwest limb of the anticline is an old prospect, now caved, but in the dump are fragments of good coal. South of the Nanaimo river, except in the limbs of the Extension anticline, the farther continuation of the seam is problematical, but the position of the western outcrop of the horizon has been fairly well determined. Because of the thick mantle of Colwood sands and gravels of the Nanaimo delta, the extent of the anticline southeast of the Extension anticline, and the position of the outcrop of the seam horizon are only assumed. Since the seam is so well developed where it crosses the Nanaimo river, both at its western outcrop and in the northeastern limb of the Extension anticline, the continuation of the seam for some distance south of the Nanaimo river is very probable. South of Haslam creek the seam horizon outcrops in the valley to the northeast of Mt. Hayes ridge in the northeasterly and steeply dipping monocline of this vicinity. The seam was not seen by the writer, but coal is reported to have been found in Bush creek, where crossed by the outcrop of the seam horizon. The eastward extent of the seam is unknown, but it doubtless extends with a variable thickness beyond the outcrop of the Newcastle and Douglas seams, at a depth of 800 to 1,200 feet, and may extend considerably farther.

STRUCTURE.

The thickness of the Wellington seam varies where mined, from virtually nothing to nearly 30 feet, and has perhaps an average thickness of 4 to 7 feet. This extreme variation is best described further by considering the structure of the seam and associated measures.

The floor of the seam is virtually always the firm, but thin bedded to flaggy, East Wellington sandstone. In places, there are lentils of shale between the seam and the floor, and interbeds of shale in the sandstone floor. Less commonly certain beds in the sandstone are pebbly and pass into conglomerate. The roof, on the contrary, varies in character. Most commonly it is a sandy shale, carbonaceous and even coaly in places. It varies in thickness from nothing up to 20 or 25 feet, and near East Wellington is overlain by sandstone, but near Extension by the typical Extension conglomerates. Near Extension, the conglomerate itself is in many places the roof of the seam. In a few places the roof is sandstone.

Near East Wellington the seam contains no persistent partings. In places, usually in the swells, the seam consists entirely of clean coal with only a very few small bony lentils or partings of soft dirty coal or "rash", an inch or less in thickness and seldom of a lateral extent of even 10 or 15 feet. In other places, usually in the pinches, the seams consist entirely of rash. Near Extension the more undisturbed portions of the Wellington seam do contain more or less persistent partings. There the seam frequently consists of three benches of coal separated by rash as indicated by the following sections (Figure 3). Other portions of the seam show the three benches of coal separated not only by rash, but also by thick partings of shale (Figure 4).

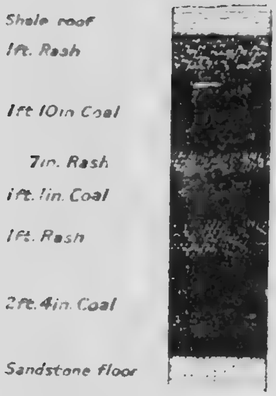

Fig. 3. Sections of the Wellington seam, where relatively undisturbed, near Extension.

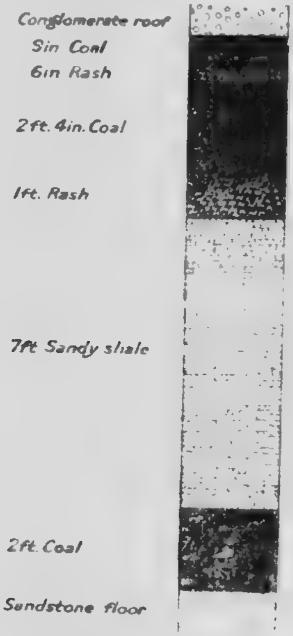

Fig. 4. Section of the Wellington seam, with thick shale parting.

The character of the rash is indicated by the following proximate analysis by F.G. Wait of the Mines Branch, Dept. of Mines, of a sample of rash collected by the writer from the Wellington seam at Extension:—

Moisture	1·59
Volatile combustible	24·15
Fixed carbon	19·29
Ash	54·97
	100·00

Other impurities besides the partings and the dirty broken coal are of little consequence. The coal contains more or less pyrite, especially the bony coal and rash, and very thin veinlets or films of calcite traversing the irregular joints of the coal are numerous, but probably do not increase the ash content greatly.

The most conspicuous feature of the seam is its variability in thickness caused chiefly by minor faults, folds, or bends usually in the roof, while the floor is fairly regular and even, although a few sharp rolls do occur in it. These features are well illustrated at East Wellington where the seam in places pinches gradually to virtually nothing and then suddenly thickens to 10 or 12 feet. Although the floor may be nearly smooth, the roof in passing from the thin to thick portion of the seam rolls sharply, and often irregularly upward. In some places the roof is even overturned, at least 25 feet in one place. These sharp rolls are locally called "faults." Invariably at the thin places or "pinches" the coal is dirty and slickensided, while in the thick places, or "swells" it is clean, black in colour, with a sub-brilliant lustre, and broken only by a few irregular joints. Rash is usually found near the top and bottom of the swells, and only rarely, as described, in thin, non-persistent partings near the centre. In some places the coal is clean and unfractured against the upturned roof, but more commonly it is somewhat slickensided and even contorted. The roof at the rolls is always contorted and slickensided. The strike of the rolls corresponds with the strike of the measures, that is northwest to west, and the pinches occur in the northeast or north side of the rolls, with the corresponding swells on the opposite side. Where the seam is overlapped, the overlap is to the northeast or north.

These features are illustrated by the following sections, which are drawn to scale (Figure 5).

Near Extension, although the seam has even greater extremes in thickness, from 5 feet to 26 feet, the rolls in the roof are, as a rule, not so abrupt, although a few abrupt rolls of 3 or 4 feet do occur. Instead, at the bends of some of the larger folds affecting the entire seam, the seam pinches and is in places composed almost entirely of rash. On the limbs of the folds, the roof rolls gradually and irregularly upward forming a swell, where the seam consists, except for the rash at the top and bottom of the seam, chiefly of clean, bright, irregularly, but not greatly fractured, coal. This feature is shown by the following sections of the Wellington seam (Figure 6).

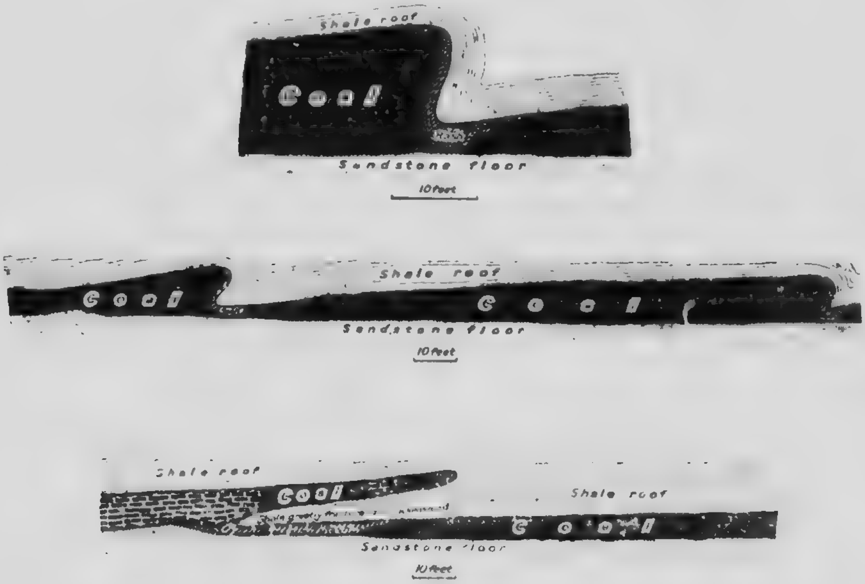

Fig. 5. Sections of the Wellington seam, near East Wellington. (Where seam is represented as broken, its position is inferred).

CHARACTER.

The coal of the Wellington seam where relatively undisturbed is black with a sub-brilliant lustre. In places it is finely laminated or bedded and in other places it is massive, the finely laminated coal containing tiny lenses of bone. The coal is crossed by irregular joints, which in the laminated coal are, however, nearly at right angles to the bedding. The coal is fairly hard and strong, breaks with a hackly fracture, and weathers well. In places it contains some pyrite and in some of the fractures thin films of calcite. In places, the coal is contorted and brilliantly polished along slickensided planes.

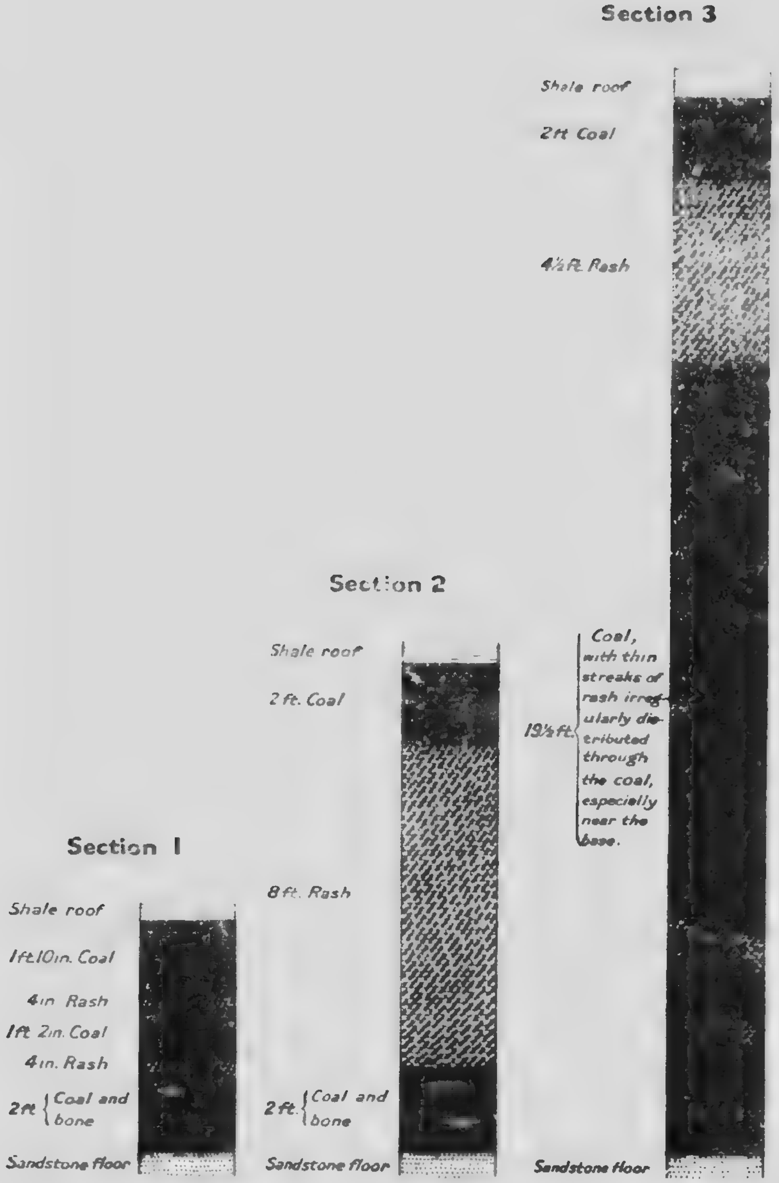

Fig. 6. Sections of the Wellington seam, near Extension; showing variation in thickness and quality. Sections 1 and 2 are 200 feet apart, and Sections 2 and 3 are 500 feet apart.

As is shown by the analyses given above, the Wellington coal is a rather high volatile bituminous coal and does not differ essentially in composition from the other Nanaimo coals. However, it appears from the tests made by Stansfield and Porter[1] to be a much better coking coal than the Newcastle and Douglas coals. At present, no coke is made from it, but it is used entirely as a steam, gas, and domestic coal.

NEWCASTLE COAL SEAM.

Distribution and Thickness.

The Newcastle coal seam occurs between the Cranberry and Newcastle formations. It extends through the west central part of the map-area, with a general N. 20° W. trend from northern Newcastle island to south of Nanaimo river. It is exposed on both sides of Newcastle island and presumably extends across the island. It outcrops to the west of the Brechin mine on Pimbury point, the Brechin shaft sunk to the seam being only 84 feet deep. In this vicinity the seam averages from 30 to 40 inches thick and contains one or more fairly persistent partings. The seam is doubtless continuous between the Brechin mine and Nanaimo although the outcrop is not exposed. It was exposed in one or two old slopes in the city of Nanaimo, and is now being mined in depth, where the seam averages 30 to 40 inches in thickness, although it is reported to have a maximum thickness of 6 or 8 feet. South of Nanaimo it outcrops for 1½ miles in the Chase River valley and is exposed in a few prospect slopes and in the Douglas slope of the Western Fuel Company. The seam averages about 6 or 8 feet thick, but contains only from 2 to 4 feet of fairly clean coal, separated by partings of coaly shale. South of Chase River the seam is of doubtful commercial quality, but is well defined as far as South Wellington and is exposed in several prospect slopes. The seam varies in thickness from 18 inches to 6 feet, but consists chiefly of dirty coal and thick partings of coaly shale. The seam is not exposed between South Wellington and the Nanaimo river, and its character and the position of its outcrop are not known. South of the Nanaimo river, what is probably a continuation of the Newcastle seam is exposed in a prospect slope in the southwest limb of the southeastward pitching syncline of the crescent-shaped cuesta between the Esquimalt and Nanaimo railway and the Extension collieries railway. The seam is 6 feet thick, but it consists chiefly of bony coal and carbonaceous shale, with lentils of coal up to 10 inches in thickness. South of the exposure the farther continuation of the seam is very doubtful. The eastward extension of the seam is unknown. It has been mined by the Western Fuel Company near Nanaimo for over a mile off shore and presumably extends much farther. South of Chase river, where the seam even at the outcrop is thin and dirty, the eastward extension is problematical and is probably not great.

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[1] Coals of Canada, Dept. of Mines, Mines Branch, Pub. No. 83, Vol. I, 1912, Part VI, pp 205-233, and table XLIV.

STRUCTURE.

Few details concerning the Newcastle seam can be given, since it was not seen by the writer where it is mined. The average thickness of the seam where mined is from 30 to 40 inches, with extremes of 20 inches and 6 or 8 feet. It is, therefore, although thinner, much more regular than the Wellington or Douglas seam. Where seen on the surface the seam contains more numerous and more regular partings. The floor of the seam is usually the typical dark green, thin bedded, flaggy or shaly sandstones of the Cranberry formation. The roof varies, according to the composition of the Newcastle formation, from a sandy shale to sandstone, grit, or even fine conglomerate. The former predominates in the vicinity of Newcastle island, Chase river, and South Wellington, and the latter in Nanaimo and near the Nanaimo river.

CHARACTER.

To judge from the few available analyses, especially that by Stansfield of the commercial coal, the Newcastle coal while not differing in any pronounced degree from the Wellington and Douglas coals, being a high volatile bituminous coal, appears to be lower in fixed carbon and actual carbon content, and higher in oxygen and ash. Neither does the coal appear to coke readily. It is used as a steam coal.

DOUGLAS COAL SEAM.

Distribution and Thickness.

The Douglas coal seam occurs in the Newcastle formation, as stated, about 25 to 100 feet above the Newcastle seam, so that its outcrop occurs from 100 to 1,000 feet to the east of the Newcastle seam dependent upon the character of the topography and the angle of dip. It extends from northern Newcastle island to south of Nanaimo river, and may extend as far south as Ladysmith. It is exposed in an old slope (Fitzwilliam mine) on the west side of Newcastle island, and is reported to be exposed on the northeast shore of the island. It outcrops at the Brechin mine, where there is a slope on the seam, and although not exposed it doubtless extends without a break to Nanaimo. The seam is not at present mined near the surface in the vicinity of northern Newcastle island and the Brechin mine, but the workings of the No. 1 and Protection mines extend in depth below Newcastle island. The thickness presumably averages about the same as farther south, about 5 feet. Near Nanaimo there are several old slopes on the seam, none of them open at present, and one or two actual exposures of the seam. Near the outcrop the seam is not more than 4 or 5 feet thick, but in many places in depth it attains a thickness of more than 10 feet, although there are corresponding thin places in the seam. South of Nanaimo its position can be accurately located by old stopes and a few exposures, as far as South Wellington. At South Wellington there are several slopes and airways in the seam and there is an exposure half a mile south of South Wellington, near the railway of the Pacific Coast Collieries. Near Chase River and South Wellington the seam averages about 5 feet in thickness, but varies in thickness from virtually nothing to over 30 feet. On the south bank of the Nanaimo river the seam is well developed and is exposed in a prospect pit on the outcrop. It is 8 feet thick and consists chiefly of fairly clean coal, with lens-like partings of soft dirty coal and some bony coal. Farther south the seam is not exposed, but in Bush creek, near the bridge of the Extension collieries railway, is an outcrop of coaly shale with coal lentils at the probable position of the outcrop of the seam, so that the extension of the seam south of the Nanaimo river is assumed, although in the southern part it may be of no commercial value. The seam extends eastward from its outcrop for at least 1½ miles and presumably considerably more. With the Newcastle seam it has been mined near Nanaimo for over a mile from shore, and farther south it has been located by several bore-holes, near the lower part of the Nanaimo river, and, as stated, has been reached recently in this vicinity by two shaft mines.

STRUCTURE.

The floor and roof of the Douglas seam vary in character from grit or fine conglomerate, as at Nanaimo, to sandy shale as in places near northern Newcastle island and South Wellington. Near South Wellington the floor is usually a rather weak sandy shale, and the roof, although stronger, varies from a sandy shale to a fine grained conglomerate with fragments of coaly material and irregular thin partings of slickensided, coaly shale. The roof consists chiefly of a shaly sandstone with sandstone layers and lenses of fine grained conglomerate. The seam varies greatly in thickness from nothing to 30 feet, and averages about 5 feet, although over large areas the average thickness of the mineable coal is 3 and 4 feet. Unlike the conditions in the Wellington seam the pinches and swells are caused chiefly by irregularities in the floor, the roof being fairly smooth. Neither are the rolls in the floor so abrupt as those in the roof of the Wellington seam. In some places the floor rolls up nearly to the roof and in other places rolls rather abruptly downward. The strike of the rolls corresponds in general with the strike of the measures, that is about N. 30° W., but varies considerably, and the rolls are not so long or so regular as those of the Wellington seam. The abrupt side of the up-rolls is usually to the southwest, and of the down-rolls to the northeast.

These features are illustrated by the following sections, which are drawn to scale (Figure 7).

At the pinches the seam is composed almost entirely of rash like that of the Wellington seam, although as a rule the rash is harder. The coal of the swells is clean, with a compact texture and rather dull to sub-brilliant lustre. It is irregularly broken into large irregularly shaped blocks. Near the pinches some of the coal is slickensided and contorted, but where these features are shown the coal contains a rather large amount of ash. The floor is almost invariably sheared and slickensided at the rolls and in places the roof is likewise. The seam both in the pinches or swells, or even where it is relatively undisturbed, contains no regular or very persistent partings, but there are thick partings or "wants" of carbonaceous and coaly shale, which in places entirely replace the seam, but which pinch rapidly in all directions (see Figure 8).

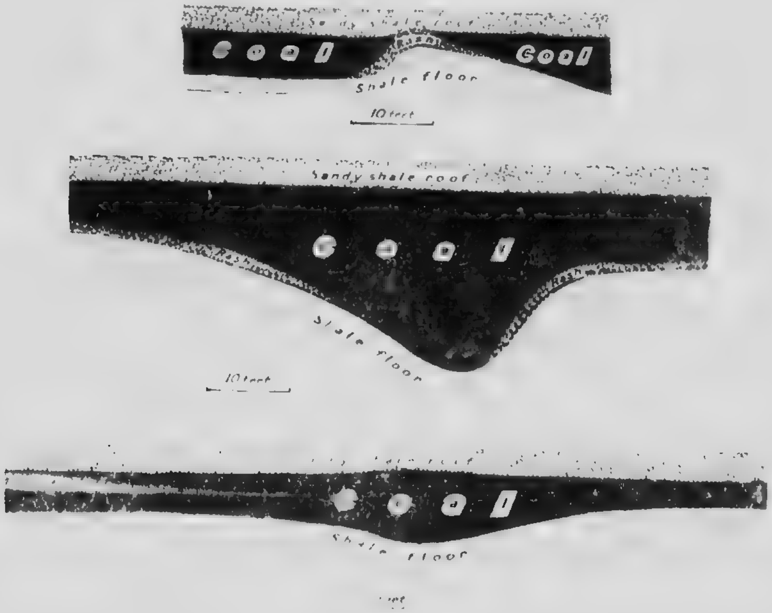

Fig. 7. Sections of the Douglas seam, showing rolls.

The seam is also displaced by rather numerous small faults, although an actual break seldom occurs, the coal having been forced along the plane or zone of dislocation (see Figure 9). More rarely the entire seam folds or wrinkles without any appreciable variation in thickness (see Figure 10).

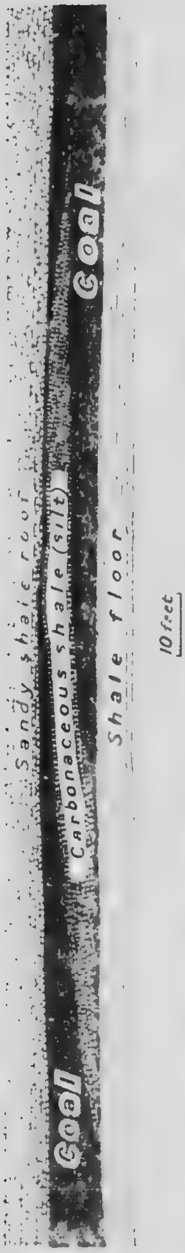

Fig. 8. Section of the Douglas seam, showing a parting of carbonaceous shale, a "want" due to silting.

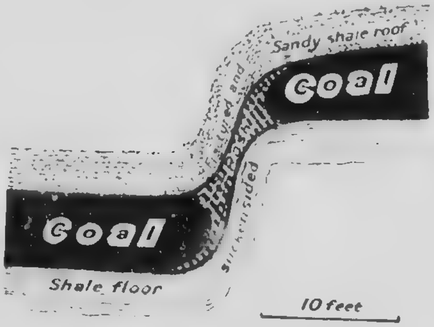

Fig. 9. Dislocation or fault in the Douglas seam.

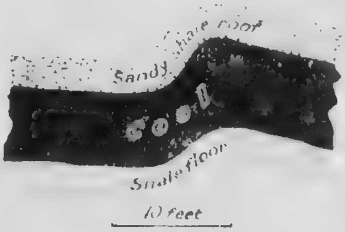

Fig. 10. Small fold or wrinkle in the Douglas seam.

Where the rolls, pinches, faults, and wrinkles occur at comparatively shallow depths, their presence is usually indicated on the surface by a small cuesta-like ridge, with a steep front slope at right angles to the bedding, and a gentle back slope nearly parallel to the bedding.

CHARACTER.

The Douglas coal is black with a sub-brilliant to brilliant lustre. It is massive and broken by irregular joints producing an irregular hackly fracture. It is fairly hard and weathers well. As in the Wellington coal, thin films of calcite occur on some of the fractures. In places where the coal has been sheared it develops highly polished, very irregular, slickensided surfaces, between which the coal has a rather dull to sub-brilliant lustre. Except where it is dirty and contains a rather large amount of ash, it is rarely contorted.

The Douglas coal is a high volatile bituminous coal, and as may be seen from the analyses, is very similar to the Wellington coal. From the analyses it appears as if the coal from Southfield and South Wellington was higher in fixed carbon and lower in ash than that from near Nanaimo, and it also appears to coke more readily. At present, the Douglas coal is used as a steam, gas, and domestic coal.

ORIGIN AND GEOLOGICAL HISTORY.

Little is known concerning the actual origin of the coal seams, but since the coal measures were deposited under rapidly varying marine and terrestrial conditions, and since the seams rest indiscriminately on sandstone, shale, and even conglomerate, there seldom being any under clay and very few fossil roots, it is not probable that the coal is the result of accumulation of vegetable matter in large, coastal plain swamps, with standing timber and luxuriant undergrowth. It is more probable that the vegetable matter accumulated in peat bogs, which may have been formed in lagoons protected from the outer, marine basin, by bay bars. It is probable, therefore, that the seams do not extend indefinitely to the northeast, below the Strait of Georgia, but are confined to a greater or less extent to the neighbourhood of the old shore of pre-Upper Cretaceous seas. Since the seams, especially where undisturbed, are dirty, the dirty coal alternating with clean coal, and in places are composed entirely of dirty coal or carbonaceous shale, silt must have been deposited in the bogs with the peat, in sufficient amount in places to form some of the "wants" of the present seams.

As described under the structural geology of the Nanaimo series, the measures were deformed by forces acting from the northeast. Local deformation occurred while at least some of the measures were unconsolidated, but the larger movements did not take place for a long period after the deposition had ceased. It appears that the local deformation caused some of the minor disturbances in the coal seams; for it looks as if, when the seams were first folded, the clean coal was softer and more plastic than the dirty coal or rash. It was, therefore, squeezed away from the tight bends, where there was an increase of vertical pressure, to the limbs of the bends or rolls, where there was a corresponding decrease in vertical pressure. Thus swells were formed, which consist, except for the rash at the top and bottom, chiefly of clean coal, while the pinches were left, composed almost entirely of rash. Since it is the sandy shale roof of the Wellington seam and the relatively weak sandy shale floor of the Douglas seam that are deformed, it appears as if the relative strength of the roof and floor determined in general the relative amount of deformation in each. It is possible that original or initial irregularities in the seams determined the location of the minor disturbances. The later and larger movements produced the large open folds and faults in which the seams are involved and presumably caused the minor faulting and wrinkling of the seams. These movements necessitated lateral adjustment by the sliding of one bed upon another; and it is probable that much of the lateral adjustment took place by sliding along the coal seams,[1] and caused some of the slickensiding and contortion of the coal as well as of the roof and floor.

Minor disturbances or local variations or interruptions of coal seams similar to those described as affecting the seams of Nanaimo field, are rather common and have been described by various writers.[1] They appear to have been formed in several different ways—by irregularities in deposition, by contemporaneous or later erosion, but, as in the Nanaimo field, chiefly by some kind of deformation. They are not only of scientific interest but of great commercial interest as well, for, as has already been pointed out,[2] "the constantly recurring industrial disputes owe their origin, in no small measure, to the difficulties experienced in framing satisfactory agreements for the "working of deficiency places" where the miner cannot under ordinary circumstances, make what he considers a fair living wage."

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[1] See, Bailey Willis, Some Coal Fields of Puget Sound: 18th. Ann. Rept. Part III, 1897, U. S. Geol. Survey, pp. 408-409.

DESCRIPTION OF MINES.

There are four operating companies in the Nanaimo coal field—the Western Fuel Company, Canadian Collieries (Dunsmuir) Company, Pacific Coast Collieries, and Vancouver-Nanaimo Coal Mining Company.

VANCOUVER-NANAIMO COAL MINING COMPANY.

The Vancouver-Nanaimo Coal Mining Company operates the New East Wellington colliery at East Wellington. The mine, opened in 1907, is located on the Wellington seam. The seam is reached through a slope or rather an inclined shaft, paralleling an old slope driven in the Little Wellington seam. The Wellington seam in the mine is fairly even, with a low dip 5 to 10 degrees to the northeast, but to the southwest the seam is faulted in a series of steps, and outcrops at the surface to the southwest of the surface plant with a steep dip to the northeast. The mine is worked on the pillar and stall method, the pillars being drawn and the roof supported by cogs. There has been a little long wall mining, but the method is not adaptable owing to the great variation in thickness of the seam, which has already been described. The coal is undercut where possible but is chiefly shot from the solid. Horses and winches are used for hauling in the mine. Since the roof is rather weak, the mine is well timbered, and, as stated, when the pillars are drawn the roof is supported by cogging. The mine is ventilated by a fan and the ventilation is good, there being virtually no gas. The output for the mine in 1911 was 72,918 long tons.

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[1] The following references give the fullest treatments of the subject.

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Willis, B.—"Some Coal Fields of Puget Sound:" 18th Ann. Rept., Part III, 1896-97. U. S. Geol. Survey, pp. 410-412.

Woolnough, W. G.—"Stone Rolls in Bulli Coal Seam of New South Wales:" Jour. Roy. Soc. N. S. Wales, Vol. 44, 1910, pp. 334-340

[2] Woolnough, W.G., "Stone Rolls" in the Bulli Coal Seam in New South Wales. Jour. Roy. Soc. N.S. Wales, Vol. 44, 1910, p. 334.

CANADIAN COLLIERIES (DUNSMUIR) COMPANY.

In the Nanaimo field the Canadian Collieries (Dunsmuir) Company operates the Extension collieries opened up in 1899 and formerly worked by the Wellington Collieries Company. The Extension collieries consist of four mines, all on the Wellington seam. Mines Nos. 1, 2, and 3 are situated in the southwest limb of the Extension anticline and mine No. 4 in the northeast limb, the mine being situated about 1½ miles southeast of the entrance to the adit or "tunnel" to the other three mines, in the town of Extension. The seam in mines Nos. 1, 2, and 3 is broken by a reversed strike fault of about 500 feet displacement. Mine No. 1 is situated in the northeast, downthrown side of the fault and mines Nos. 2 and 3 are in the southwest upthrown side. The mines are at present reached by an adit, or as it is called a "tunnel" about a mile long, which crosses the southwestward dipping seam in the downthrown side of the fault, and the fault, to the southwestward dipping seam in the upthrown side. No. 2 mine is situated to the southeast of the end of the tunnel and No. 3 mine to the northwest. Both portions of the faulted seam extend to the surface and the slopes of No. 2 and No. 3 mines are kept open and used for airways and roadways (See Plate III B). In the downthrown side, the seam dips to the southwest at angles varying from 5 to 20 degrees, although near the fault it wrinkles and in places turns up against the fault zone. In other places it seems to dip under the fault, which as described[1] appears in places to have a low dip to the southwest and to be of the nature of an overthrust. In the upthrown side the seam has been folded into a broad syncline or shallow basin, which in its northern part, in No. 3 mine, is broken by a reversed strike fault of a displacement from nothing to about 150 feet,[1] the displacement increasing to the northwest.

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[1] See Structural Geology of the Nanaimo series.

The mine is worked chiefly by the pillar and stall method, the pillars being drawn. In places in No. 2 mine where the roof is conglomerate, the seam is mined by the long wall method. The coal is mined by hand and by various systems, depending upon the thickness and character of the seam. Mules and winches are used to haul the coal to the collecting roads. It is then taken to the surface through the tunnel by electric locomotives. Since in most places the roof is sandy shale the mine is well timbered, and when the pillars are drawn the roof is supported by cogging. Each mine is well ventilated by a separate fan system.

At No. 4 mine the seam, which is reached by a shaft 280 feet deep, dips to the northeast at an angle of about 15 degrees, outcropping about 1,000 feet to the southwest of the shaft. The mine is worked by the pillar and stall method. The mine is timbered and cogged and ventilated through a separate shaft southwest of the main shaft. The output from all of the Extension mines in 1911 was 331,576 long tons.

WESTERN FUEL COMPANY.

The Western Fuel Company operate two collieries in the Nanaimo field, the Nanaimo and the Northfield or Brechin collieries, As already mentioned the company have recently opened up a new shaft mine on the Indian Reserve at the mouth of the Nanaimo river, and a slope, abandoned during 1912, in the Newcastle seam, outcropping in the valley of Chase river. The following description of the mines, which were not examined by the writer, is largely condensed from T. C. Denis' description in the Coals of Canada, Pub. No. 83, Vol. I, Part II, pp. 112-13, Dept. of Mines, Mines Branch, 1912, and from Inspector Thomas Morgan's report for 1911, Minister of Mines, B.C., pp. K 224 to K 230.

At the Nanaimo colliery the Douglas and Newcastle seams are mined. The seams are reached through the No. 1 shaft (Esplanade) near the shore in the southern part of the city of Nanaimo,

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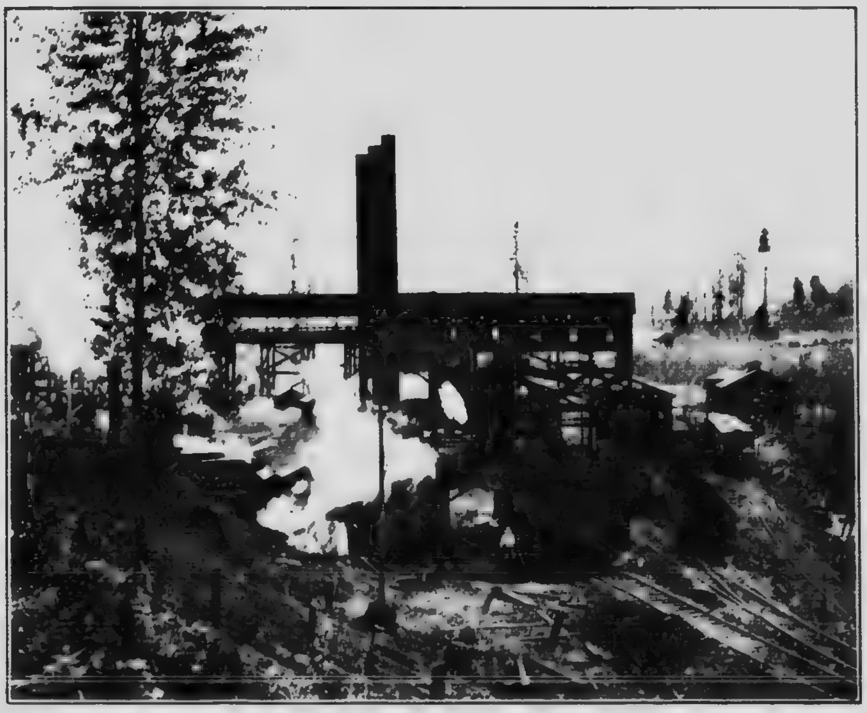
[1] The structure through the mines is shown in structure section A.B.

A



B

A. Northfield colliery or Brechin mine of the Western Fuel Company, Pimbury point.
B. South Wellington colliery of the Pacific Coast Collieries.

640 feet to the Douglas seam and 700 feet to the Newcastle, and by the Protection Island shaft on the southern point on Protection island. about 588 feet to the Douglas seam and about 652 feet to the Newcastle. The underground workings, which extend below Nanaimo harbour and the Nanaimo River delta, are very extensive, and from face to face on opposite sides of the mine is over 5 miles.[1] The general dip of the seams is about 10 degrees to the east. The Newcastle seam is worked by the long wall method, the coal being undercut by machines, and the Douglas seam is worked by the pillar and stall method, and as a rule, all the coal is removed where the cover exceeds 500 feet.[2] The underground haulage is partly by electric looomotives and partly by endless rope, to the bottom of No. 1 shaft. The mine is ventilated by fans, most of the air going down the Protection shaft and returning through the No. 1 shaft. The total production of this colliery in 1911 was 411,909 long tons.

At the Brechin mine situated on Pimbury point (see Plate XII A), the coal mined at present is all from the Newcastle seam, although the workings connect with the Douglas seam. The seam is reached by a slope and by a shaft 84 feet deep,[3] and the workings extend below Newcastle island. The general dip of the seams is about 5 degrees to the southeast but turns to the eastward in depth and increases slightly. The mining is by the long wall method and undercutting machines are used. Haulage is by endless rope to the bottom of the shaft. The ventilation is by fan, the downcast shaft being on Newcastle island. The output of the mine for 1911 was 161,852 long tons.

PACIFIC COAST COLLIERIES.

The Pacific Coast Collieries who took over the property of the Pacific Coast Coal Mines in 1912, operate in the Nanaimo field the Fiddick or South Wellington colliery at South Wellington (see Plate XII B) and have recently opened up a new shaft mine 610 feet deep, at Morden, about a mile east of South Wellington. The South Wellington colliery is located on the

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[1] Report Minister of Mines, B.C., 1911, p. K 226.

[2] Denis, T. C., Coals of Canada, Pub. No. 13, Vol. 1, Part II, Mines Branch, Dept. of Mines, 1912, p. 112.

[3] Denis, T. C., Coals of Canada, Pub. No. 83, Vol. I, Part II, Mines Branch, Dept. of Mines, 1912, p. 113.

Douglas seam and is operated through two slopes in the seam. The seam has a general dip of about 10 degrees to the northeast, although the seam is involved in several minor rolls, and as described is subject to great variation in thickness by the irregularities of the floor The coal is mined by the pillar and stall method, and where the coal is thinner and of fairly uniform thickness it is worked by a modified long wall method. The coal is shot from the solid. In the mine the coal is handled by electric winches and horses. The roof has to be well timbered and where the pillars are drawn and where the long wall method is employed, has to be supported by cogging. The mine is ventilated by a fan. The production in 1911 was 205,048 long tons.

SANDS AND GRAVELS.

The Colwood sands and gravels forming the Nanaimo delta, furnish an abundant supply of sand and gravel. Except in a very limited way these have been quarried only near the Esquimalt and Nanaimo railway, a mile and a half south of South Wellington, and near the railway to the Extension collieries, half a mile south of Nanaimo river (see Plate XI A) for filling and grading purposes on the railways. The deposits could be used for all other purposes to which sand and gravel may be put. But although they could be quarried cheaply they are not favourably situated for cheap water transportation to the city of Vancouver, the chief market at present for sand and gravel.

Some of the sands and gravels in the upper portion of the Puyallup interglacial deposits have been quarried in a small way near Departure bay and west of Nanaimo, for road and railway ballast and for other purposes.

CLAY.

The clays of the superficial deposits of the Nanaimo map-area are as a rule very sandy, weak, and of poor plasticity and have been utilized only to a small extent for the manufacture of common brick. Some brick has been manufactured from the clays of the Puyallup interglacial deposits underlying the marshy flat bordering the Millstone river midway in its course, but at present no brick is made. There are other localities where common brick could be made from the clays not only from the Puyallup deposits but from the Colwood sands and gravels, but, as stated, by far the greater number of the surface clays are sandy and non-plastic, and would make a weak brick of inferior grade.

The various shales of the Nanaimo series, notably those of Haslam, Cedar District, and Northumberland formations, are also sources of shale-clay, which may be used for brick and various kinds of semi-porous ware and stoneware. The greater portion of the shales are very sandy and of very low plasticity. Also they contain numerous interbeds of sandstones, as well as sandstone concretions and sandstone dykes (see Plate VII). The shales also contain too large a percentage of iron, lime, and alkalies to be considered fireclays, as they are sometimes called. In fact, Professor H. Ries[1] reports that the shales tested from the Nanaimo series are not very refractory, as the Haslam shale from East Wellington softens at cone 1 (2102° F., 1150° C.) while the lower shale of the Northumberland formation from Gabriola island vitrifies at cone 3 (2174° F., 1190° C.). Certain portions of the Haslam shales, notably at an horizon about 100 feet below the top, some of the lower shales of the Northumberland formation, and to a less extent some of the Cedar District shales, are comparatively plastic and may be used in a stiff mud auger machine or dry-press for the manufacture of brick, tile, and cheaper grades of stoneware. With the exception of thin local beds, the shales of the other horizons are very sandy and impure and may be left out of consideration. One of the local shale beds associated with the Wellington coal seam was mined to a small extent in the Extension collieries. It was used by the British Columbia Pottery Company, to increase the refractoriness of the surface clays quarried near the plant in Victoria west, where sewerpipe and similar wares are manufactured. At present there is no shale mined in the Extension collieries. None of the other shales were being utilized at the time of the writer's examination in 1911, although in East Wellington, just to the west of the Nanaimo map-area, the shale from the upper portion of the Haslam formation had been tested, and the products of the test were apparently of good grade. In 1912, however, brick was manufactured in East Wellington from the Haslam shale, and on Gabriola island, near False narrows, from the lower shale of the Northumberland formation.

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[1] Personal communication.

STONE.

Some of the sandstones of the Nanaimo series furnish a building stone of fair quality. Three of the sandstones have been quarried—the Protection, the DeCourcy, and the Gabriola. The Protection sandstone has been quarried on Newcastle island, and a small amount has been quarried in the city of Nanaimo, near the Western Fuel Company's wharf, but the latter quarry has been abandoned for some time. The Newcastle Island quarry (see Plate VI A) is situated on the west shore of the island opposite Pimbury point. A single bed of a uniform and rather fine grained sandstone, about 16 feet thick, striking N. 15° W., and dipping 5° N.E., has supplied most of the sandstone which has been quarried. It is greyish white on fresh fracture but weathers quickly to a dirty or brownish grey. It is composed of angular grains of quartz and clear or white weathered feldspar, shreds of biotite and some of muscovite, and a few green and red grains seen microscopically to consist of epidote and cherty or jaspery rocks. The sandstone is chiefly cemented by secondary silica and is rather friable. It is not regularly or greatly jointed, and irregular blocks as large as 4 feet by 6 feet by 3 feet have been quarried. However, the sandstone can be easily cut to any smaller required size. Sandstone for building stone has been the only product. The quarry has not been in operation for a few years.

The DeCourcy sandstone has been quarried at Jack point, east of Nanaimo. It has been obtained from two beds, 15 and 30 feet in thickness, separated by about 5 feet of sandy shale and shaly sandstone, and even the thick beds of sandstone contain shaly sandstone partings (see Plate VI B). The sandstone is medium to coarse grained, light greenish grey on

[illegible] 25 feet thick.

5314 — p. 122

fresh fracture, but weathering to buff. It is composed of angular to rounded grains of quartz, feldspar, and meta-andesite, and flakes of biotite and muscovite, in a greenish matrix consisting chiefly of chlorite. On microscopic examination, it is seen to contain accessory epidote, magnetite, and titanite. The cement is siliceous and ferruginous. The fresh rock is strong, although rather soft, but hardens with seasoning. The bedding is regular, N. 30° W., 25° N.E., but the cross joints are irregular. The joints are few, and large blocks can be quarried. Building stone has been the only product. The quarry was not in operation during 1911.

The Gabriola sandstone is quarried at North Gabriola on Gabriola island (see Plate XIII). The stone is obtained from a 25 to 40 foot bed of sandstone, near the base of the Gabriola formation, whose attitude at the quarries is about N. 25° W., 18° N.E. The sandstone is light greenish grey, weathering to a darker and more brownish grey, medium to coarse grained, and composed of angular grains of quartz, feldspar, and meta-andesite, and flakes of biotite with accessory muscovite, epidote, and magnetite, in a greenish matrix composed largely of chlorite and serpentine. The cement is chiefly calcite, which is present in large aomunt. The sandstone contains many concretions up to 3 feet in diameter, and these are the most harmful feature of the stone. The stone is strong and hardens with seasoning. There is no regular system of jointing, but large blocks may be obtained. Stone for buildings and foundations has been the only product. None of the quarries have been in operation for a few years.

Up to the present time there has been no commercial production of crushed stone from the Nanaimo map-area. The rocks of the Nanaimo series are of little value as sources of crushed stone, but the less altered and less sheared of the Vancouver volcanics afford a material of fair grade. Stone of this quality conveniently situated for shipping is to be found north of Departure bay.

LIME.

The impure limestones or calcarenites of the Haslam formation which are exposed on the north shore of Departure bay, have been opened up by a test quarry to obtain material to be burned for lime. However, it may be seen from the analysis of the rock, given below, that the percentage of lime is too small and the amount of insoluble material too large for the rock to be used for lime. Also, since the impurities mixed with the calcium carbonate consist of fine quartz sand, feldspar, and chlorite, the rock is not suitable for the manufacture of either natural or Portland cement.

Partial analysis of impure limestone from Departure bay, H. A. Leverin, analyst.

Insol. mineral matter	15·42
Ferric oxide and alumina	5·40
Lime[1]	42·41
Magnesia[1]	0·94

---

[1] Equivalent to calcium carbonate 75·73 and magnesium carbonate 1·96.

METALLIC DEPOSITS.

The Vancouver meta-volcanics of the Nanaimo map-area are greatly fractured and sheared, and many of the shear zones are impregnated with a little pyrite and chalcopyrite. One or two prospects have been located in these mineralized shear zones, but the resulting mineral bodies are too small and irregular and too low grade to be of any commercial value.

The gabbro-diorite and Saanich granodiorite of Mt. Hayes are traversed by aplite and quartz veins and by shear zones. Both kinds of veins and some of the shear zones are mineralized, the aplite veins and the shear zones very sparingly, and only with pyrite, but a quartz vein on the Thistle claim contains chalcopyrite and bornite in attractive amounts. Two prospect adits in aplite veins in gabbro-diorite, about half a mile east of north from the summit of Mt. Hayes, failed to show more than traces of pyrite and chalcopyrite in the aplite, although, in one instance, some faulting has taken place forming a gouge up to 3 inches thick along one side of the vein. Another prospect on the north bank of Bush creek on the northeast slope of the Mt. Hayes ridge, over a mile south of east of the summit, is located in a large inclusion of gabbro-diorite in the Saanich granodiorite. The inclusion has been greatly sheared, forming a shear zone

5 to 20 feet wide, striking about N. 35° W. and dipping 55° S.W., and the rock has been partly altered to chlorite. It is also slightly mineralized with pyrite and chalcopyrite.

On the Thistle claim located about a mile north of east of the summit of Mt. Hayes, is a prospect in a quartz vein, in the Saanich granodiorite, that carries bornite and chalcopyrite. The development work consists of two adits, one 25 feet above the other, each with a short level and with a stope connecting them. The vein has a strike about N. 45° W., with a dip of 30° S. W. It has a thickness of 2 inches to 1 foot, with an average thickness of about 4 inches, and can be traced for about 100 feet in length. It then branches and thins out to nothing. The vein apparently follows the chief or master jointing of the granodiorite, in places separated from the wall rock by a thin gouge, and along the foot-wall is an aplite dyke 3 to 5 inches wide. The granodiorite of the foot-wall, near the aplite dyke, is fractured and somewhat sheared, cut by quartz-epidote and sericite veinlets, and sparingly mineralized, but is only slightly more altered than the normal granodiorite, which forms the hanging wall.

The vein is coarsely crystalline and consists chiefly of quartz irregularly intergrown with opaque, white weathering feldspar, and some green biotite in irregular patches and veinlets. The metallic minerals consist chiefly of chalcopyrite, bornite, and molybdenite, and form perhaps 10 per cent of the veinrock. The molybdenite occurs nearest the walls, but, in general, the vein is massive and the minerals are irregularly intergrown, although the metallic minerals seem to have been formed somewhat later than the non-metallic.

Microscopically, the vein is seen to be aplitic in nature, the quartz, which greatly predominates, forming interlocking anhedral grains, that are in places micrographically intergrown with the feldspar, which consists of microcline and microperthite. The non-metallic accessories consist of biotite and titanite; and sericite and epidote occurring in the cracks of the quartz grains are secondary.

The close relationship of the vein and the aplite dyke, and the comparative freshness of the granodiorite walls indicate that the vein was formed at high temperature and pressure, and probably under magmatic conditions during the "after effects" of the granodiorite intrusion. The metallic minerals in the vein have undergone virtually no enrichment and but very slight oxidation or other change.

Commercially the vein, as has been shown by systematic and careful prospecting, is too small and too low grade to be profitably mined.

SOILS.

The soils of the Nanaimo map-area are virtually all transported or drift soils and consist of a mixture of the superficial deposits with decayed vegetable and animal matter, called humus. Consequently their character at any locality is directly dependent upon the immediately underlying superficial deposit, being sandy or pebbly where underlain by sands or gravels, and clayey where underlain by clays. Thus the general character of the soils and their distribution is approximately shown on the accompanying map of the superficial deposits.

The soils formed from the Puyallup interglacial deposits range from fertile, fine sandy loams to dry, coarse sandy loams, which cannot hold much water and are subject to great changes of temperature and consequently are of poor fertility. The former soils occur where the subsoil is sandy or fine clayey sand. They are most common below elevations of 200 or 250 feet, especially in the valley extending from the mouth of the Nanaimo river to Ladysmith (Oyster) harbour. The latter soils are found where the subsoil is coarse sand or gravel.

The Vashon drift forms chiefly a rather coarse, sandy loam, with a considerable proportion of clay and also numerous pebbles and boulders. The soil is fertile and supports a thick forest growth and heavy underbrush. The forest has not yet been cleared to any great extent nor has much land been prepared for cultivation on account of the numerous pebbles and boulders and because the country underlain by the Vashon drift is hilly.

The Colwood sands and gravels of the Nanaimo delta usually have a surface covering of coarse gravel, and consequently their soil covering is thin and consists of a gravelly, porous loam that is comparatively sterile. Although the soil supports a fairly heavy forest growth, it does not support very much underbrush. The country underlain by the Nanaimo delta is, therefore, more open than most of the lowland of Vancouver island. Much of the forest has been cut for timber, but little of the land is under cultivation. In a few places, however, where the subsoil is one of the sandy clays of the delta or where the delta deposits are covered by fine silt, presumably deposited in shallow lakes that formed on the surface of the delta or in the sluggish streams which crossed the delta, the soil is of much greater fertility, but since the subsoil is underlain by sands and gravels, it is apt to be dry.

The swamp, valley, and delta alluvium supports in its natural condition a heavy growth of swamp vegetation and coarse grass, and where cleared and drained is productive, but is apt to become dry and light during the summer months.

The areas mapped as rock outcrops or rock debris support a fairly heavy forest growth, and in places even considerable undergrowth. The trees and underbrush find a hold in the crevices of the rocks and between the rock fragments, and derive part of their nourishment from the thin mantle of drift covering the rock outcrops or mingled with the rock debris. Such areas are, of course, entirely unsuited for agriculture of any kind and should be reserved for the growth of forest trees.

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LIST OF RECENT REPORTS OF GEOLOGICAL SURVEY.

Since 1910, reports issued by the Geological Survey have been called memoirs and have been numbered Memoir 1, Memoir 2, etc. Owing to delays incidental to the publishing of reports and their accompanying maps, not all of the reports have been called memoirs, and the memoirs have not been issued in the order of their assigned numbers, and, therefore, the following list has been prepared to prevent any misconceptions arising on this account. The titles of all other important publications of the Geological Survey are incorporated in this list.

Memoirs and Reports Published During 1910.

REPORTS.

Report on a geological reconnaissance of the region traversed by the National Transcontinental railway between Lake Nipigon and Clay lake, Ont.—by W. H. Collins. No. 1059.

Report on the geological position and characteristics of the oil-shale deposits of Canada—by R. W. Ells. No. 1107.

A reconnaissance across the Mackenzie mountains on the Pelly, Ross, and Gravel rivers, Yukon and North West Territories—by Joseph Keele. No. 1097.

Summary Report for the calendar year 1909. No. 1120.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 1. *No. 1, Geological Series.* Geology of the Nipigon basin, Ontario—by Alfred W. G. Wilson.

Memoir 2. *No. 2, Geological Series.* Geology and ore deposits of Hedley Mining district, British Columbia—by Charles Camsell.

Memoir 3. *No. 3, Geological Series.* Palæoniscid fishes from the Albert shales of New Brunswick—by Lawrence M. Lambe.

Memoir 5. *No. 4, Geological Series.* Preliminary memoir on the Lewes and Nordenskiöld Rivers coal district, Yukon Territory—by D. D. Cairnes.

Memoir 6. *No. 5, Geological Series.* Geology of the Haliburton and Bancroft areas, Province of Ontario—by Frank D. Adams and Alfred E. Barlow.

Memoir 7. *No. 6, Geological Series.* Geology of St. Bruno mountain, Province of Quebec—by John A. Dresser.

MEMOIRS—TOPOGRAPHICAL SERIES.

Memoir 11. *No. 1, Topographical Series.* Triangulation and spirit levelling of Vancouver island, B.C. 1909—by R. H. Chapman.

Memoirs and Reports Published During 1911.

REPORTS.

Report on a traverse through the southern part of the North West Territories, from Lac Seul to Cat lake, in 1902—by Alfred W. G. Wilson. No. 1006.

Report on a part of the North West Territories drained by the Winisk and Upper Attawapiskat rivers—by W. McInnes. No. 1080.

Report on the geology of an area adjoining the east side of Lake Timiskaming—by Morley E. Wilson. No. 1064.

Summary Report for the calendar year 1910. No. 1170.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 4. *No. 7, Geological Series.* Geological reconnaissance along the line of the National Transcontinental railway in western Quebec—by W. J. Wilson.

Memoir 8. *No. 8, Geological Series.* The Edmonton coal field, Alberta—by D. B. Dowling.

Memoir 9. *No. 9, Geological Series.* Bighorn coal basin, Alberta—by G. S. Malloch.

Memoir 10. *No. 10, Geological Series.* An instrumental survey of the shore-lines of the extinct lakes Algonquin and Nipissing in southwestern Ontario—by J. W. Goldthwait.

Memoir 12. *No. 11, Geological Series.* Insects from the Tertiary lake deposits of the southern interior of British Columbia, collected by Mr. Lawrence M. Lambe, in 1906—by Anton Handlirsch.

Memoir 15. *No. 12, Geological Series.* On a Trenton Echinoderm fauna at Kirkfield, Ontario—by Frank Springer.

Memoir 16. *No. 13, Geological Series.* The clay and shale deposits of Nova Scotia and portions of New Brunswick—by Heinrich Ries, assisted by Joseph Keele.

MEMOIRS—BIOLOGICAL SERIES.

Memoir 14. *No. 1, Biological Series.* New species of shells collected by Mr. John Macoun at Barkley sound, Vancouver island, British Columbia —by William H. Dall and Paul Bartsch.

Memoirs and Reports Published During 1912.

REPORTS.

Summary Report for the calendar year 1911. No. 1218.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 13. *No. 14, Geological Series.* Southern Vancouver island—by Charles H. Clapp.

Memoir 21. *No. 15, Geological Series.* The geology and ore deposits of Phoenix, Boundary district, British Columbia—by O. E. LeRoy.

Memoir 24. *No. 16, Geological Series.* Preliminary report on the clay and shale deposits of the western provinces—by Heinrich Ries and Joseph Keele.

Memoir 27. *No. 17, Geological Series.* Report of the Commission appointed to investigate Turtle mountain, Frank, Alberta, 1911.

Memoir 28. *No. 18, Geological Series.* The geology of Steeprock lake, Ontario —by Andrew C. Lawson. Notes on fossils from limestone of Steeprock lake, Ontario—by Charles D. Walcott.

Memoirs and Reports Published During 1913.

REPORTS, ETC.

Museum Bulletin No. 1: contains articles Nos. 1 to 12 of the Geological Series of Museum Bulletins, articles Nos. 1 to 3 of the Biological Series of Museum Bulletins, and article No. 1 of the Anthropological Series of Museum Bulletins.

Guide Book No. 1 Excursions in eastern Quebec and the Maritime Provinces, parts 1 and 2.

Guide Book No. 2. Excursions in the Eastern Townships of Quebec and the eastern part of Ontario.

Guide Book No. 3. Excursions in the neighbourhood of Montreal and Ottawa.

Guide Book No. 4. Excursions in southwestern Ontario.

Guide Book No. 5. Excursions in the western peninsula of Ontario and Manitoulin island.

Guide Book No. 8. Toronto to Victoria and return *via* Canadian Pacific and Canadian Northern railways, parts 1, 2, and 3.

Guide Book No. 9. Toronto to Victoria and return *via* Canadian Pacific, Grand Trunk Pacific, and National Transcontinental railways.

Guide Book No. 10. Excursions in northern British Columbia and Yukon Territory and along the North Pacific coast.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 17. *No. 28, Geological Series.* Geology and economic resources of the Larder Lake district, Ont., and adjoining portions of Pontiac county, Que.—by Morley E. Wilson

Memoir 18. *No. 19, Geological Series.* Bathurst district, New Brunswick—by G. A. Young.

Memoir 26. *No. 34, Geological Series.* Geology and mineral deposits of the Tulameen district, B.C.—by C. Camsell.

Memoir 29. *No. 32, Geological Series.* Oil and gas prospects of the northwest provinces of Canada—by W. Malcolm

Memoir 31. *No. 20, Geological Series.* Wheaton district, Yukon Territory—by D. D. Cairnes.

Memoir 33. *No. 30, Geological Series.* The geology of Gowganda Mining division —by W. H. Collins.

Memoir 35. *No. 29, Geological Series.* Reconnaissance along the National Transcontinental railway in southern Quebec—by John A. Dresser.

Memoir 37. *No. 22, Geological Series.* Portions of Atlin district, B.C.—by D. D. Cairnes.

Memoir 38. *No. 31, Geological Series.* Geology of the North American Cordillera at the forty-ninth parallel, Parts I and II—by Reginald Aldworth Daly.

Memoirs and Reports Published During 1914.

REPORTS, ETC.

Summary Report for the calendar year 1912. No. 1305.

The origin of granite (micropegmatite) in the Purcell sills. Geological Series No. 13, Museum Bulletin No. 2.

MUSEUM GUIDE BOOKS.

The archæological collection from the southern interior of British Columbia —by Harlan I. Smith. No. 1290.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 23. *No. 23, Geological Series.* Geology of the coast and islands between the Strait of Georgia and Queen Charlotte sound, B.C.—by J. Austen Bancroft.

Memoir 25. *No. 21, Geological Series.* Report on the clay and shale deposits of the western provinces (Part II)—by Heinrich Ries and Joseph Keele.

Memoir 30. *No.* [illegible], *Geological Series.* The basins of Nelson and Churchill rivers —by William McInnes.

Memoir 20. *No. 41, Geological Series.* Gold fields of Nova Scotia—by W. Malcolm.

Memoir 36. *No. 29, Geological Series.* Geology of the Victoria and Saanich map-areas, Vancouver island, B.C.—by C. H. Clapp.

Memoir 52. *No. 42, Geological Series.* Geological notes to accompany map of Sheep River gas and oil field, Alberta—by D. B. Dowling.

Memoir 43. *No. 36, Geological Series.* St. Hilaire (Beloeil) and Rougemont mountains, Quebec—by J. J. O'Neill.

Memoir 44. *No. 37, Geological Series.* Clay and shale deposits of New Brunswick —by J. Keele.

MEMOIRS—ANTHROPOLOGICAL SERIES.

Memoir 48. *No. 2, Anthropological Series.* Some myths and tales of the Ojibwa of southeastern Ontario—collected by Paul Radin.

Memoirs in Press, June 25, 1914

Memoir 40. *No. 24, Geological Series.* The Archæan geology of Rainy lake—by Andrew C. Lawson.

Memoir 32. *No. 25, Geological Series.* Portions of Portland Canal and Skeena Mining divisions, Skeena district, B.C.—by R. G. McConnell.

Memoir 19. *No. 26, Geological Series.* Geology of Mother Lode and Sunset mines, Boundary district, B.C.—by O. E. LeRoy.

Memoir 22. *No. 27, Geological Series.* Preliminary report on the serpentines and associated rocks, in southern Quebec—by J. A. Dresser.

Memoir 39. *No. 35, Geological Series.* Kewagama Lake map-area, Quebec—by M. E. Wilson.

Memoir 41. *No. 38, Geological Series.* The "Fern Ledges" Carboniferous flora of St. John, New Brunswick—by Marie C. Stopes.

Memoir 47. *No.* [illegible] *Geological Series.* Clay and shale deposits of the western provinces, Part III—by Heinrich Ries.

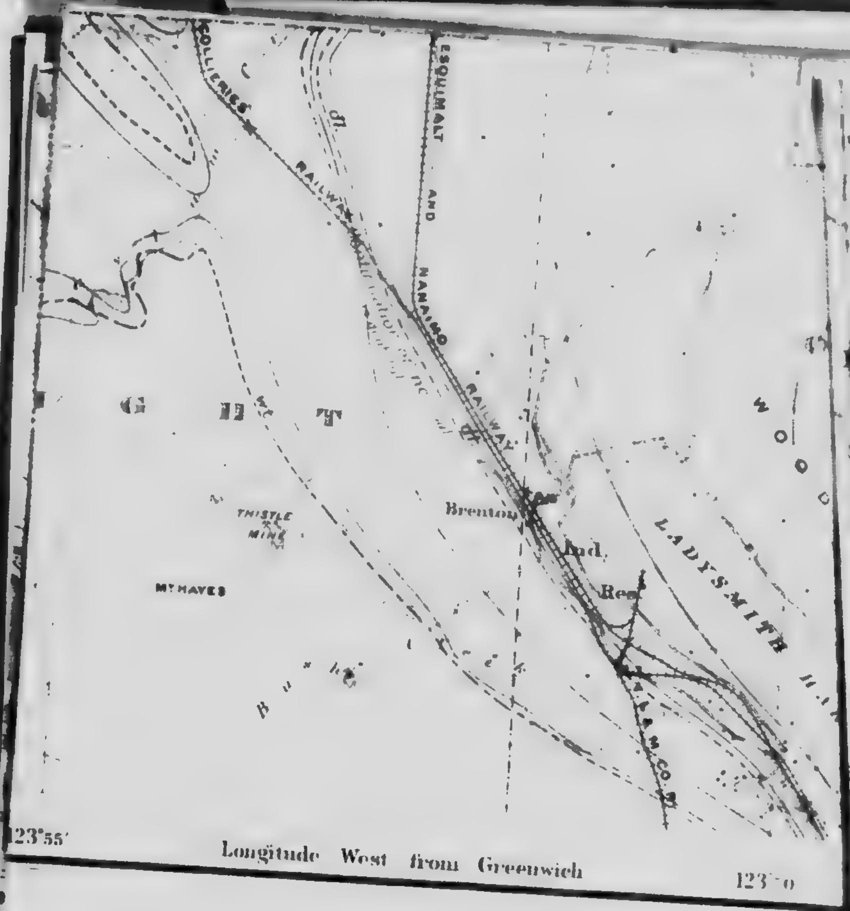
Memoir 51. *No. 43, Geological Series.* Geology of the Nanaimo map-area—by C. H. Clapp.

Memoir 53. *No. , Geological Series.* Coal fields of Manitoba, Saskatchewan, Alberta, and eastern British Columbia (revised edition)—by D. B. Dowling.

Memoir 42. *No. 1, Anthropological Series.* The double-curve motive in northeastern Algonkian art—by Frank G. Speck.

Memoir 45. *No. 3, Anthropological Series.* The inviting-in feast of the Alaska Eskimo—by E. W. Hawkes.

Memoir 49. *No. 4, Anthropological Series.* Malecite tales—by W. H. Mechling.



MAP 160 A

Issued 1916

NANAIMO SHEET

VANCOUVER ISLAND

BRITISH COLUMBIA

Scale $\frac{1}{62,500}$

Miles

Kilometres

Note. For practical purposes assume
1 MILE TO 1 INCH

MICROCOPY RESOLUTION TEST CHART
(ANSI and ISO TEST CHART No. 2)
1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2
APPLIED IMAGE Inc
1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

LEGEN

List of Working Mines

Lantzville Nanaimo Coal Mining Company New East Wellington Mi
Canadian Collieries (Dunsmuir) Company Inland and Number One Mi
Number Three Mine
Number Two Mine
Number Four Mine
Western Fuel Company Nanaimo or Number One Mine
Northfield or Brechin Mine
Protection Island Mine
Reserve Mine
Pacific Coast Collieries Fiddick or South Wellington Mine
Morden Mine

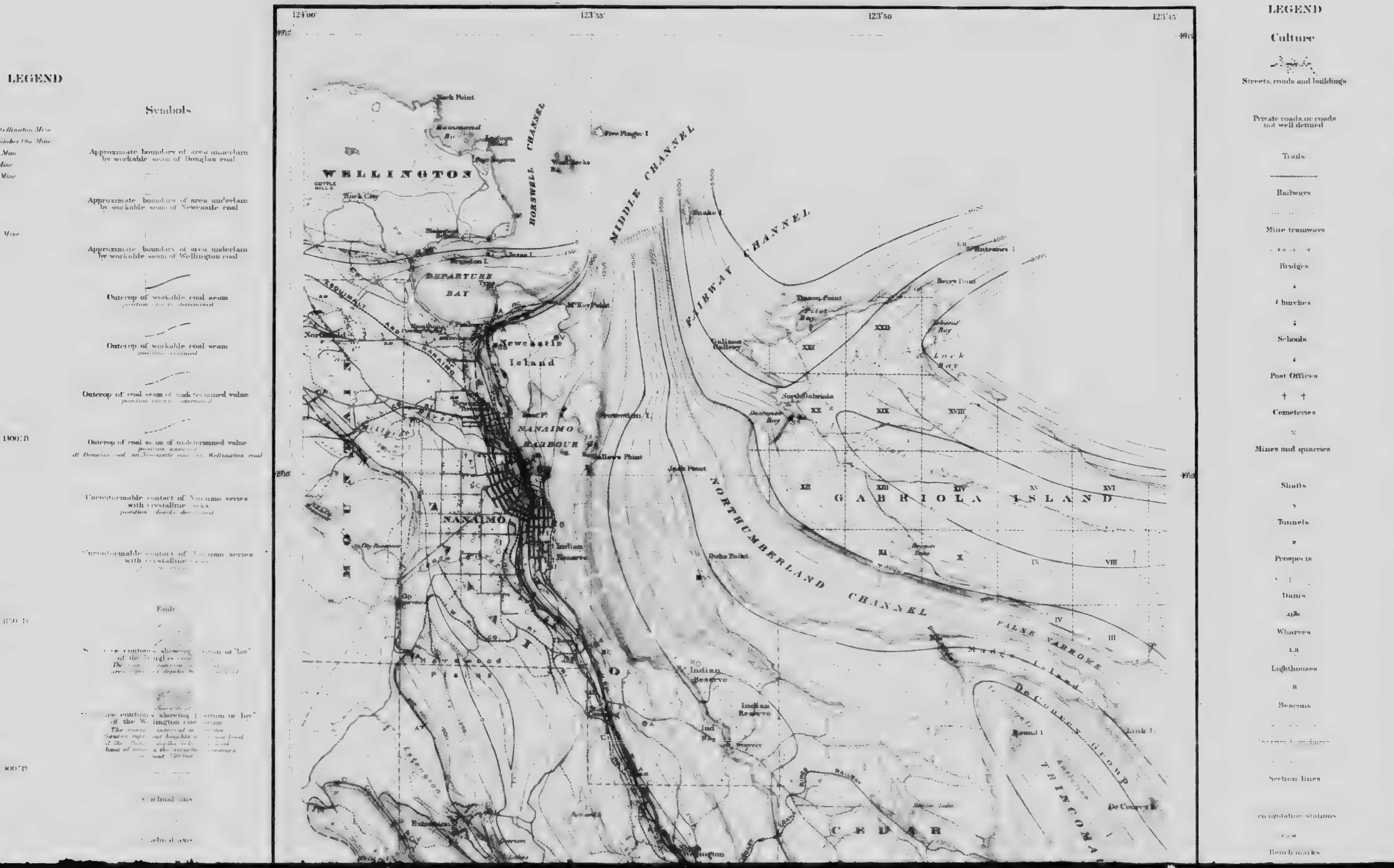
Generalized Section

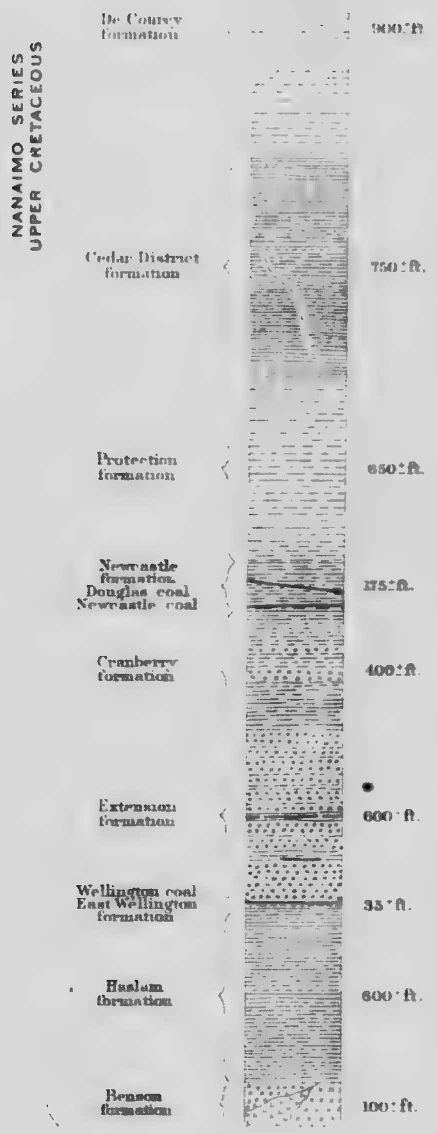
Canada
Department of Mines

HON P. E. BLONDIN, MINISTER; R. G. MCONNELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

ECONOMIC GEOLOGY


LEGEND
Wellington Mine
Number One Mine
Mine
Mine
Mine
Mine
1000 ft
1150 ft
600 ft
Symbols
Approximate boundary of area underlain by workable seam of Douglas coal
Approximate boundary of area underlain by workable seam of Newcastle coal
Approximate boundary of area underlain by workable seam of Wellington coal
Outcrop of workable coal seam position closely determined
Outcrop of workable coal seam position assumed
Outcrop of coal seam of undetermined value position closely determined
Outcrop of coal seam of undetermined value position assumed
D. Douglas coal N. Newcastle coal W. Wellington coal
Unconformable contact of Nanaimo series with crystalline rocks position closely determined
Unconformable contact of Nanaimo series with crystalline rocks
Fault
Structure contours showing position or "lay" of the Douglas coal
Structure contours showing position or "lay" of the Wellington coal seam
Synclinal axis
Anticlinal axis
124°00'
123°55'
123°50
123°45'
WELLINGTON
DEPARTURE BAY
Newcastle Island
NANAIMO HARBOUR
NANAIMO
GABRIOLA ISLAND
NORTHUMBERLAND CHANNEL
FAIRWAY CHANNEL
MIDDLE CHANNEL
HORSWELL CHANNEL
FALSE NARROWS
DE COURCY GROUP
CEDAR
Five Finger I.
Snake I.
Entrance I.
Berry Point
Lock Bay
Jack Point
Duke Point
Gallows Point
Protection I.
Indian Reserve
De Courcy I.
LEGEND
Culture
Streets, roads and buildings
Private roads or roads not well defined
Trails
Railways
Mine tramways
Bridges
Churches
Schools
Post Offices
Cemeteries
Mines and quarries
Shafts
Tunnels
Prospects
Dams
Wharves
Lighthouses
Beacons
Section lines
Triangulation stations
Bench marks



St... ture contours showing ...ition or "lay" of the ...uglas coal seam
The con... interval ... feet ... ures rep...nt depths be... sea level.

Structure contours showing position or "lay" of the Wellington coal seam
The contour interval is ... feet ... figures represent heights above sea level ... the figures depths below sea level ... limit of error in the structure contours ... about 250 feet

Anticlinal axis

Synclinal axis

○ 8
Coal mine shaft
numeral refers to numbers in accompanying list

→ 10
Coal mine slope or tunnel
numeral refers to numbers in accompanying list

○ V
Ventilating shaft

→ V
Ventilating slope

○ A
Abandoned coal mine shaft

→ A
Abandoned coal mine slope

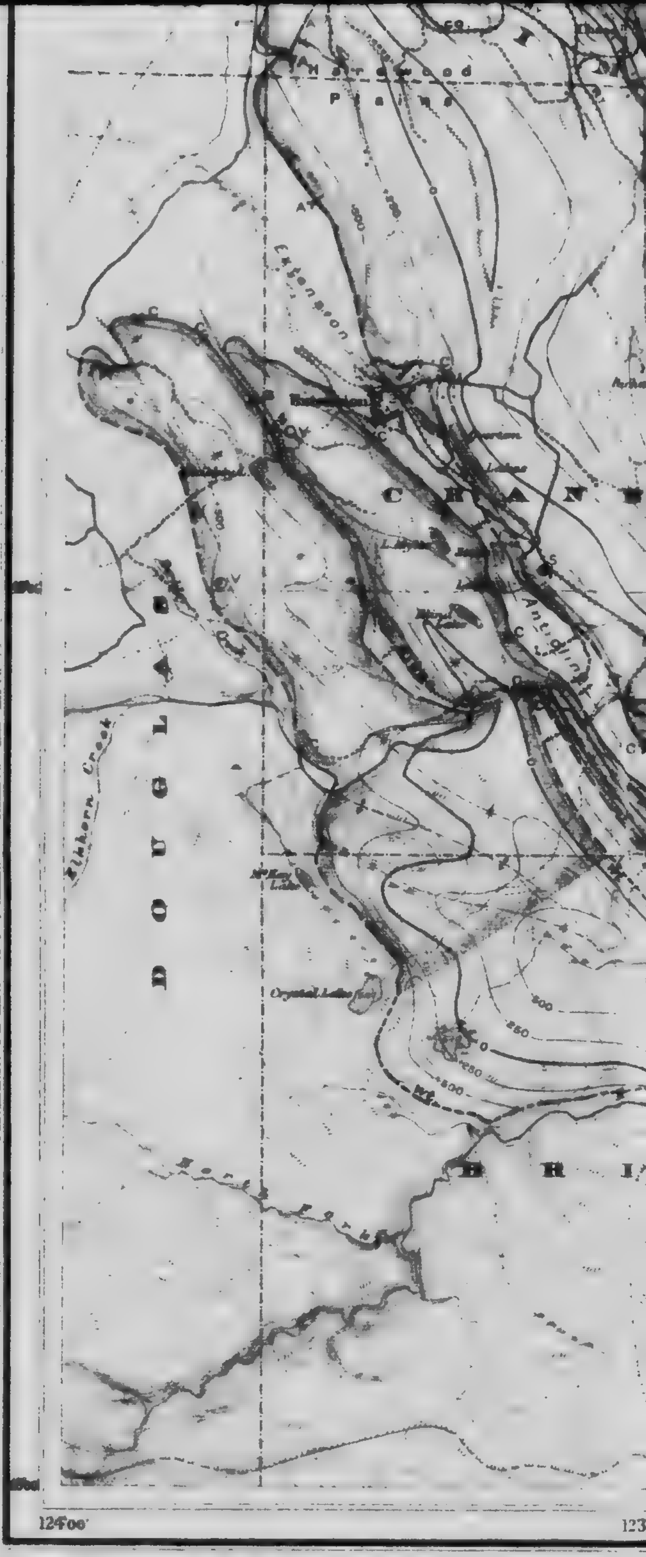
× C
Coal prospect

× M
Mineral prospect

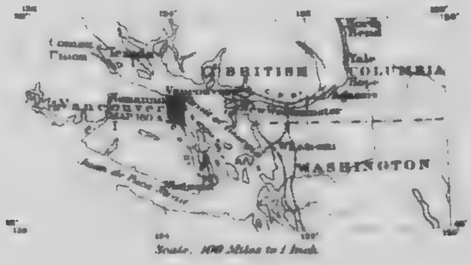
■ SS
Sandstone quarry

▨ S-G
Sand and gravel bank

▨ CY
Clay pit

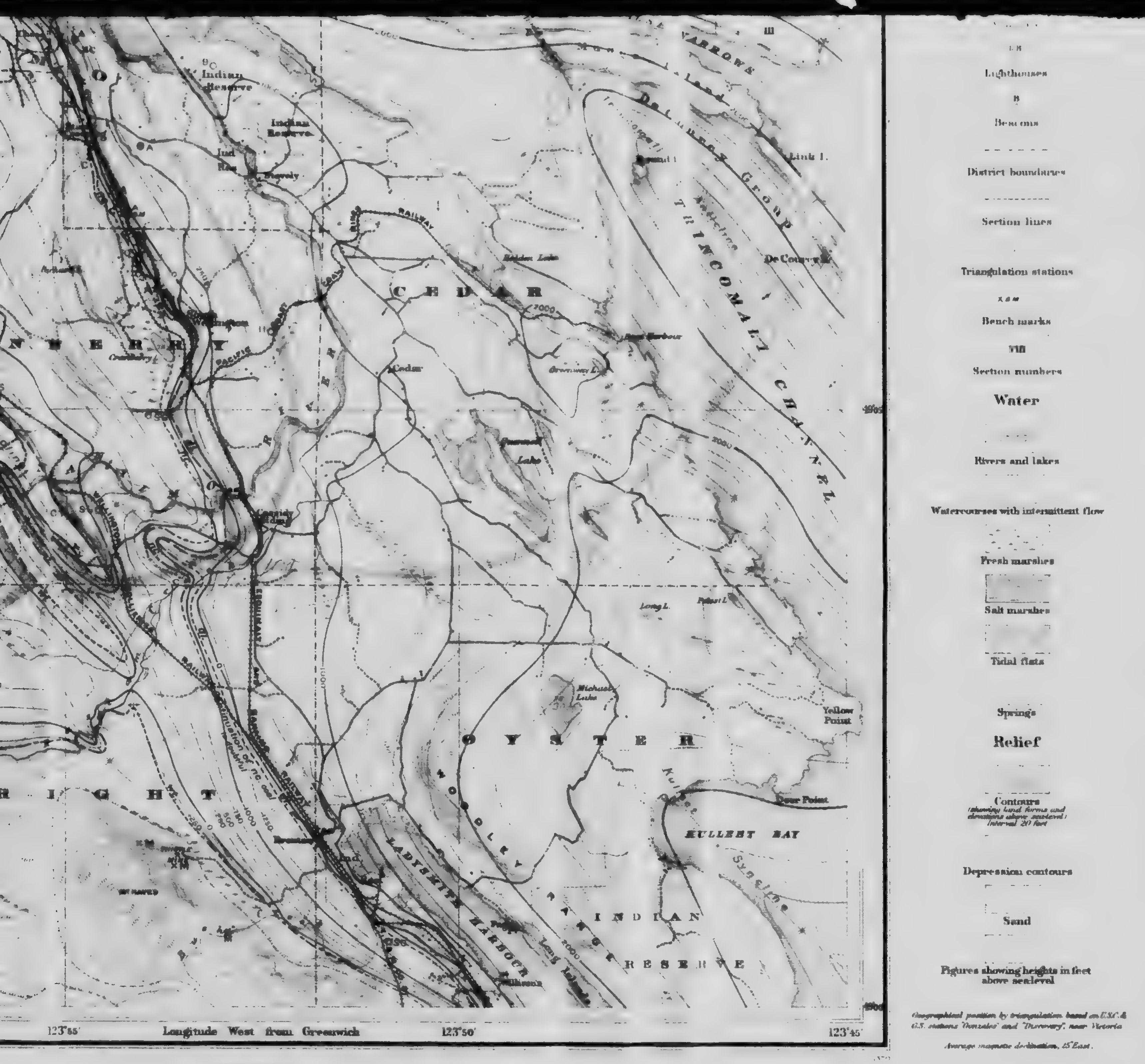


C.O. Senécal, *Geographer and Chief Draughtsman*
G.G. Aitken and A. McGregor, *Draughtsmen*



Scale, 100 Miles to 1 Inch.

To accompany Memoir by C. H. Clapp.



Geographical position by triangulation based on U.S.C. & G.S. stations "Gonzales" and "Discovery", near Victoria

Average magnetic declination, 25° East.

MAP 160 A
(Issued 1916)

NANAIMO SHEET
VANCOUVER ISLAND
BRITISH COLUMBIA

Scale, 62,500

Miles

Kilometres

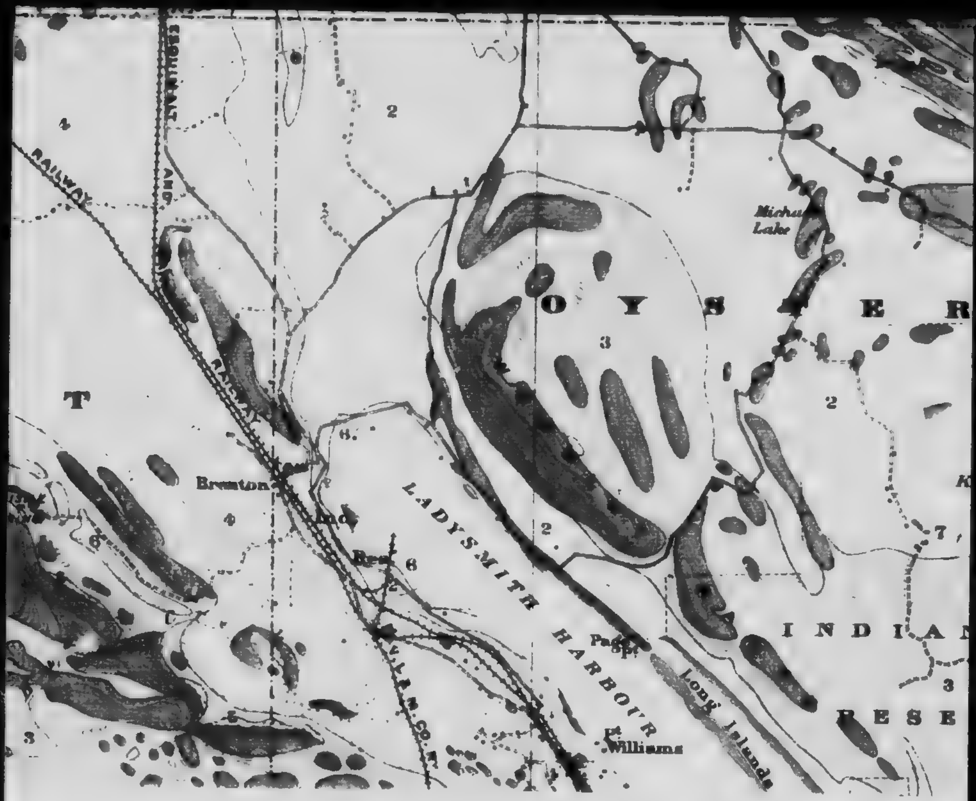
Note. For practical purposes assume
1 MILE TO 1 INCH

GEOLOGY

C.H. CLAPP	*1911*

TOPOGRAPHY

R.H. CHAPMAN (IN CHARGE)	*1910*
B.R. MACKAY	*1910*
F.S. FALCONER	*1910*
S.C. MCLEAN (TRIANGULATION)	*1909*



MAP 159A
Issued 1916

NAIMO SHEET
ANCOUVER ISLAND
BRITISH COLUMBIA

Scale $\frac{1}{62500}$
Miles
1 2 3
Kilometres
1 2 3 4 5

ote. For practical purposes assume
I MILE TO I INCH

GEOLOG

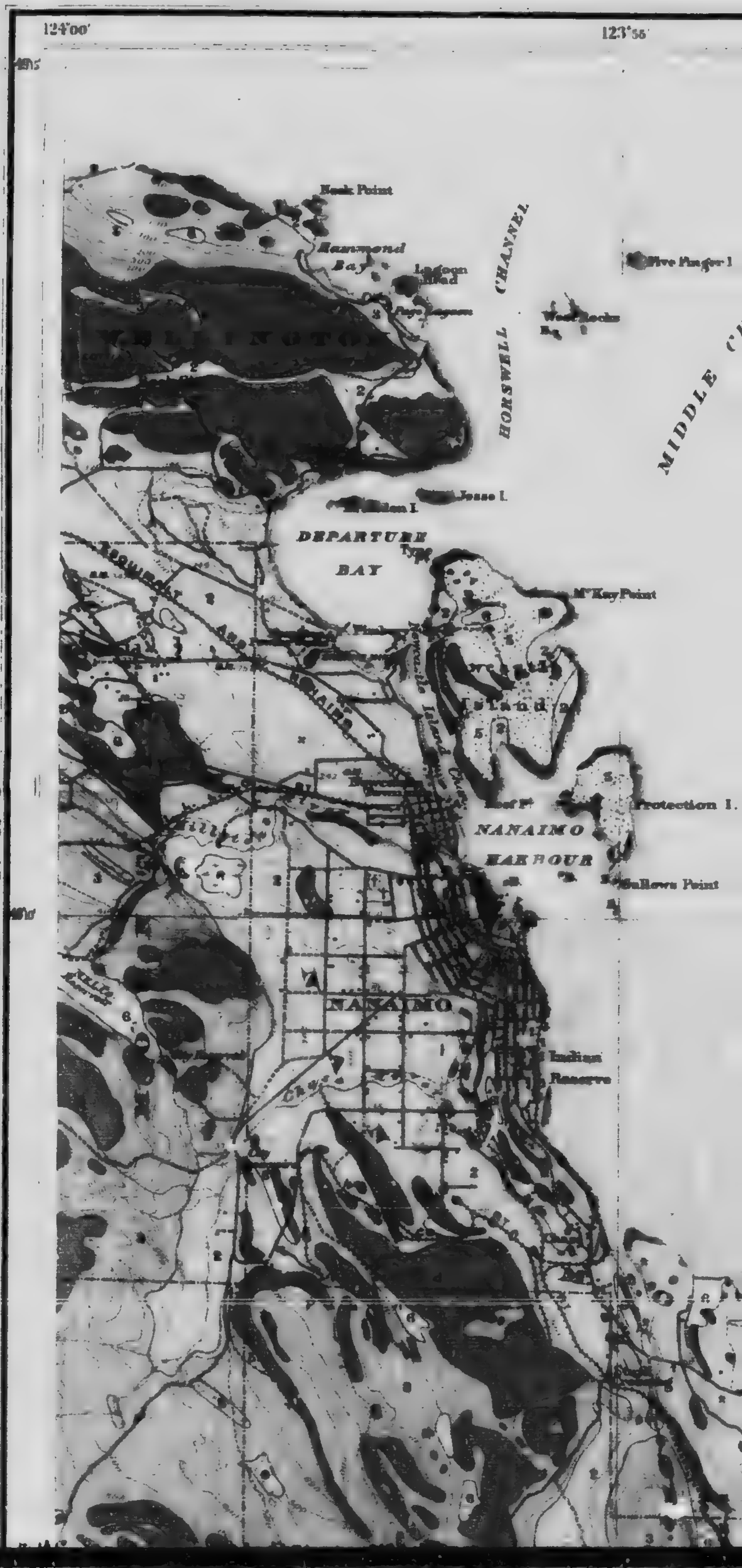
C H CLAPP

TOPOGRA

R H CHAPMAN, IN CHARGE
B R MACKAY
F.S FALCONER
S.C. McLEAN, (TRIANGULATIO

HON P E BLON

SUPERFICIAL GEOLOGY



LEGEND

QUATERNARY

POST-GLACIAL EPOCH

7
Beach alluvium

6
Valley, swamp and delta alluvium

5
Rock debris
includes sand and clay, and small areas of till

VASHON GLACIAL EPOCH

4
Colwood sand and gravel
stage of glacial retreat

3
Vashon drift
stage of glacial occupation

PUYALLUP INTER GLACIAL EPOCH

2
Puyallup clay, sand and gravel
in places strewn with boulders or covered by thin mantle of Vashon drift,

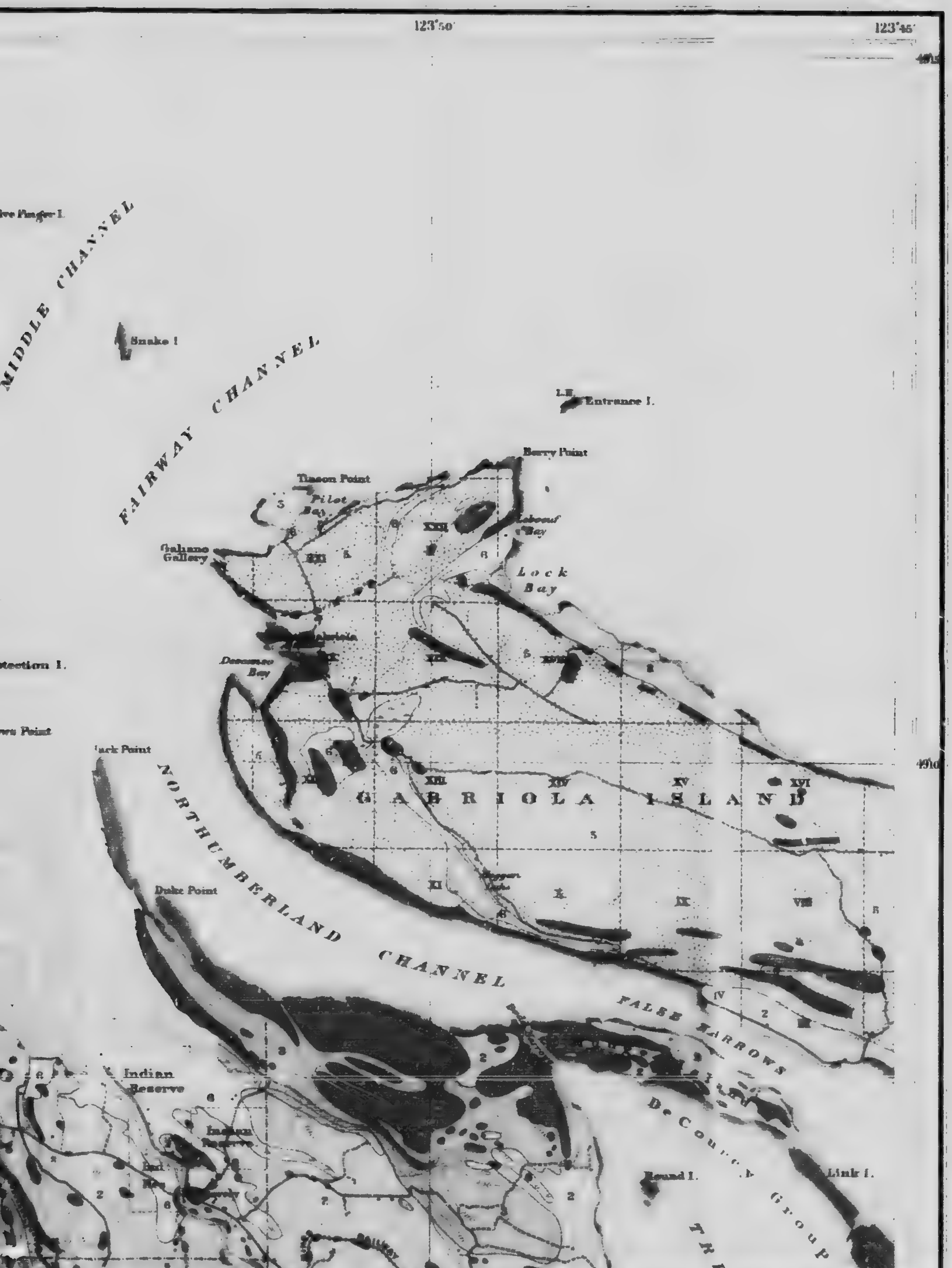
ADMIRALTY GLACIAL EPOCH

1

Canada
Department of Mines

n P. E. Blondin Minister. R. G. McConnell, Deputy Minister

GEOLOGICAL SURVEY



LEGEND

Culture

Streets, roads and buildings

Private roads, or roads not well defined

Trails

Railways

Mine tramways

Bridges

Churches

Schools

Post Offices

† †

Cemeteries

⚒

Mines and quarries

Shafts

Tunnels

Prospects

Dams

Wharves

L.H.

Lighthouses

B

Beacons

District boundaries

Section lines

[illegible]
[illegible]

PUYALLUP
INTERGLACIAL EPOCH

2

[illegible] clay, sand and gravel
[illegible] with boulders [illegible]
[illegible] of Vashon drift

ADMIRALTY GLACIAL EPOCH

1

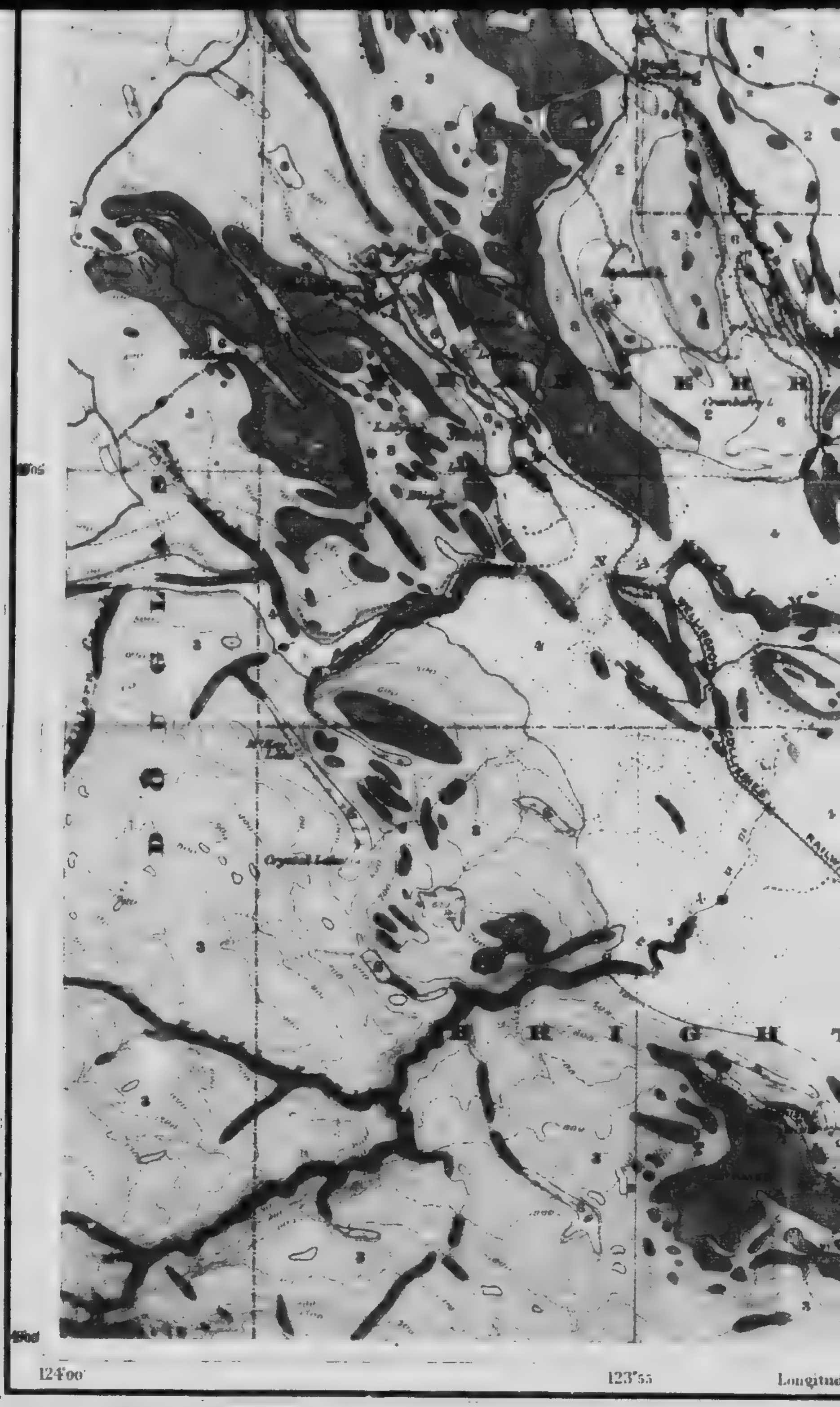
Admiralty till
not shown on map

Rock outcrops

Symbols

Geological boundary
position approximate

Glacial striae



C.O Senecal, *Geographer and Chief Draughtsman*
G.G. Aitken *and* A.McGregor, *Draughtsmen*

Scale 100 Miles to 1 Inch

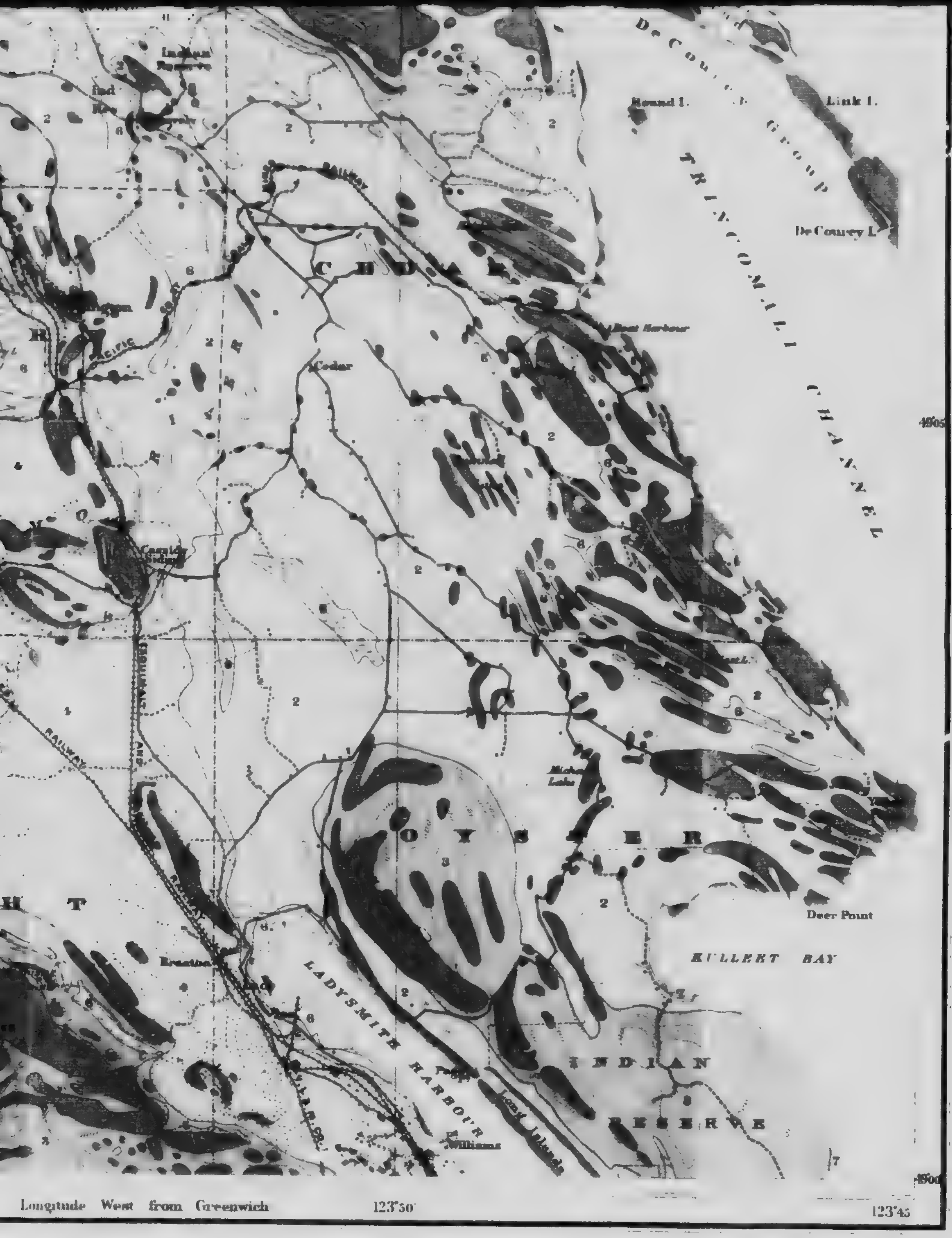
NANA

VANC

BRI

Note. For

To accompany Memoir by C.H.Clapp



Beacons

District boundaries

Section lines

Triangulation stations

x B M
Bench marks

VIII
Section numbers

Water

Rivers and lakes

Watercourses with intermittent flow

Fresh marshes

Salt marshes

Tidal flats

Springs

Relief

Contours
showing land forms and elevations above sea level Interval 20 feet

Depression contours

Sand

Figures showing heights in feet above sea-level

Geographical position by triangulation based on U.S.C. & G.S. stations "Gonzales" and "Discovery", near Victoria

Average magnetic declination, 25° East

MAP 159A.
Issued 1916

ANAIMO SHEET
VANCOUVER ISLAND
BRITISH COLUMBIA

Scale $\frac{1}{62,500}$

Miles

Kilometres

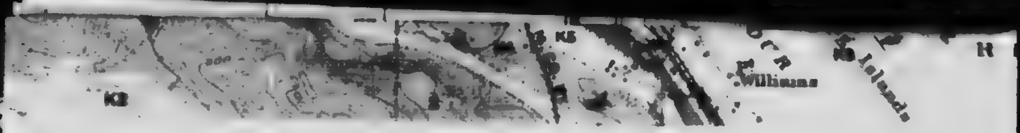
Note. For practical purposes assume
I MILE TO I INCH

GEOLOGY

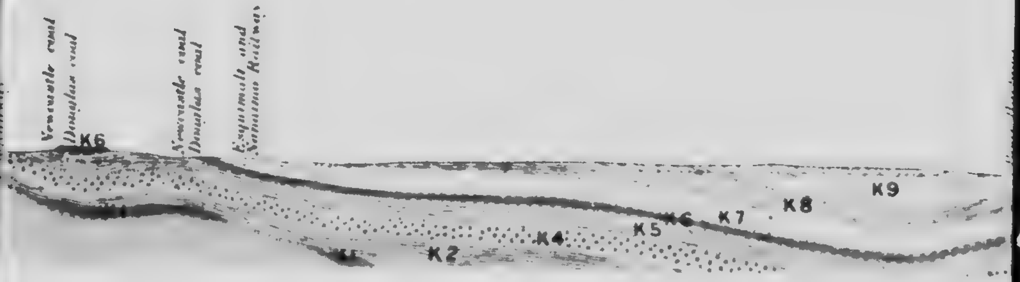
C. H. CLAPP	19

TOPOGRAPHY

R. H. CHAPMAN, IN CHARGE	1910
B. R. MACKAY	1910
F. S. FALCONER	1910
S. C. McLEAN, (TRIANGULATION)	1909



Longitude West from Greenwich 123°50'



Structural section along line C D

Scale, horizontal and vertical $\frac{1}{62,500}$

MAP 158 A

Issued 1916

NANAIMO SHEET

VANCOUVER ISLAND

BRITISH COLUMBIA

C.H.CLAPP

T

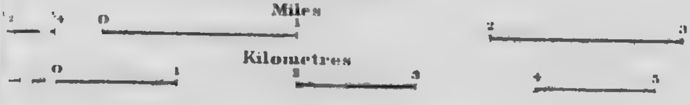
R H CHAPMAN

B R MACKAY

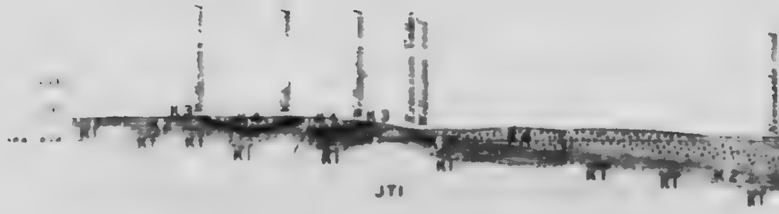
F.S. FALCONER

S.C. McLEAN.

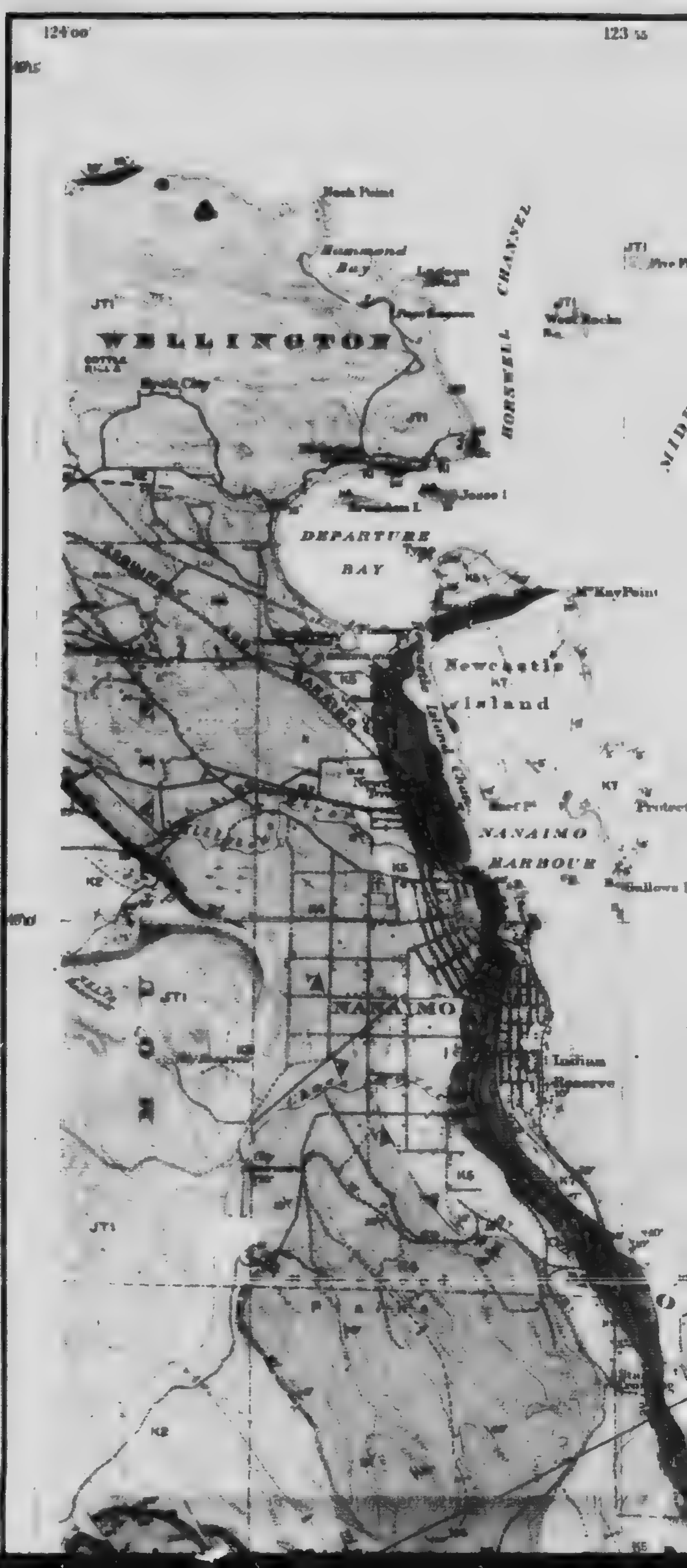
Scale, $\frac{1}{62,500}$



Note. For practical purposes assume
1 MILE TO 1 INCH



GEOLOGY



LEGEND

TERTIARY
EOCENE ?

d
Dacite porphyrite
dyke

K10
Gabriola formation
chiefly sandstone

Northumberland formation
conglomerate, sandstone and shale

K9
De Courcy formation
chiefly sandstone

K8
Cedar District formation
chiefly shale

K7
Protection formation
chiefly sandstone

UPPER CRETACEOUS
NANAIMO SERIES

K6
Newcastle formation
grit and sandy shale
contains the Douglas coal seam

K5
Cranberry formation
shale, sandstone, coal, sandy shale and some coarse sandstone and conglomerate

K4
Extension formation
chiefly conglomerate, some shale, sandstone and small coal seams

East Wellington formation
chiefly sandstone

Symbols

Coal seams
actual exposure

Coal seams
position and occurrence determined by mining
dl Douglas seam, nc Newcastle seam, wt Wellington seam

Geological boundary
contact observed

Geological boundary
probable error of location less than 100 feet

Geological boundary
probable error of location less than 500 feet

Geological boundary
(position assumed)

Fault
probable error of location less than 100 feet

Fault
probable error of location less than 400 feet

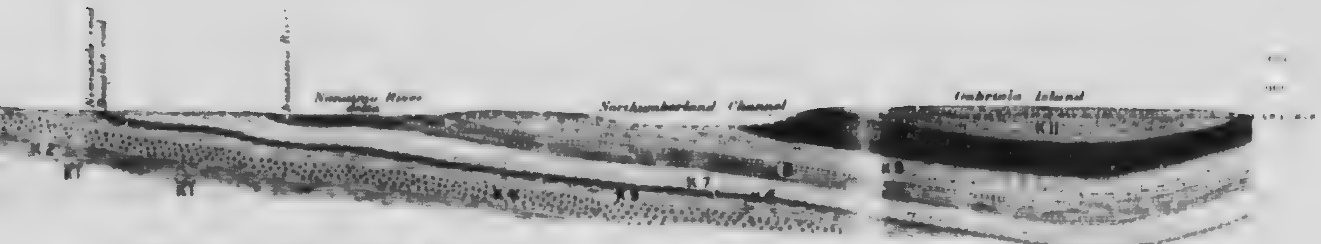
Probable fault
position assumed

Downthrow side of fault

Canada
Department of Mines

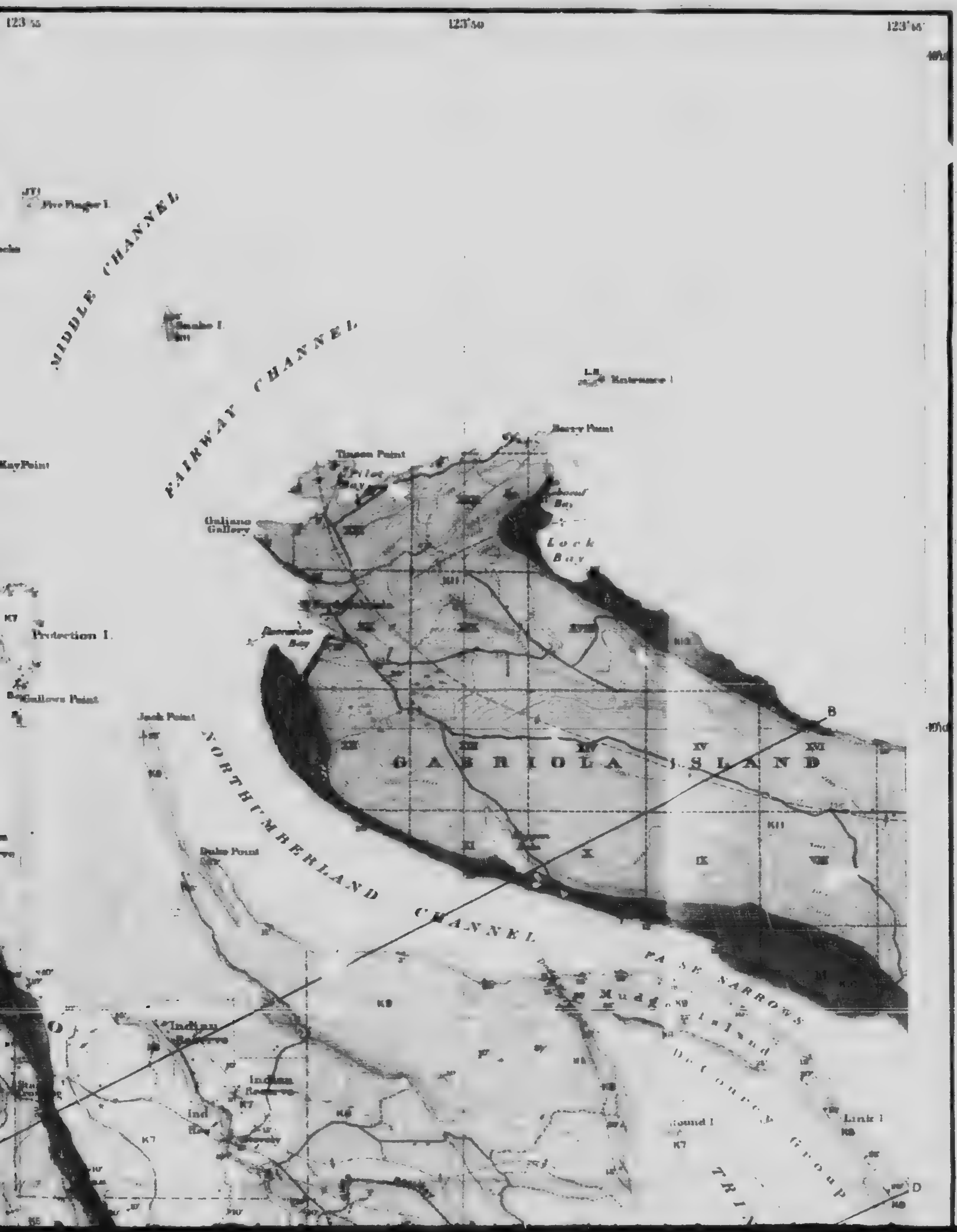
Hon P.E. Blondin, Minister R.G. McConnell, Deputy Minister

GEOLOGICAL SURVEY



Structural section along line AB

Scale, horizontal and vertical, 62,500



LEGEND

Culture

Streets, roads and buildings

Private roads or roads not well defined

Trails

Railways

Mine tramways

Bridges

Churches

Schools

Post Offices

† †

Cemeteries

Mines and quarries

Shafts

Tunnels

Prospects

Dams

Wharves

Lighthouses

Beacons

District boundaries

Section lines

MESOZOIC

[illegible]

[illegible]

K2

[illegible] formation

K1

Benson formation
[illegible]

UPPER JURASSIC AND POSSIBLY LOWER CRETACEOUS

GRANITIC INTRUSIVES

Sicker gabbro porphyrite
masses and dykes

2

Saanich granodiorite

1

Gabbro diorite
peripheral facies of Saanich granodiorite

LOWER JURASSIC AND TRIASSIC

VANCOUVER GROUP

JT2

Sicker series
slates and quartzose metamorphic sediments

JT1

Vancouver volcanics
meta andesite and meta basalt

[illegible]

Downthrow side of fault

Upthrow side of fault

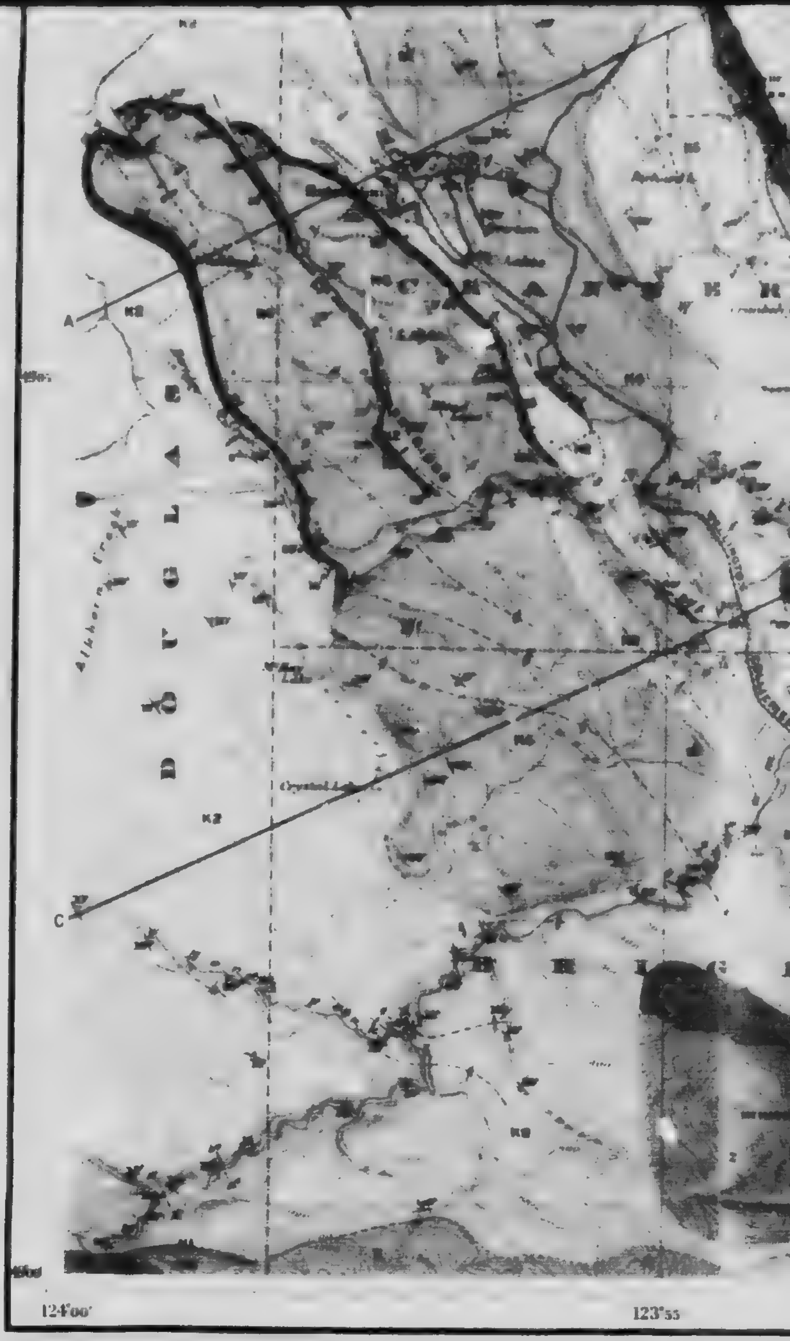
Dip and strike

Vertical strata

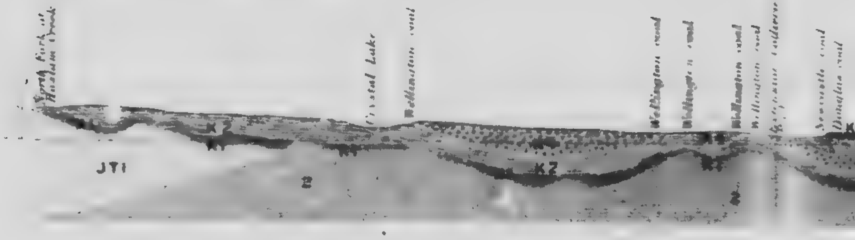
Anticline and anticline axis

Syncline and syncline axis

Fossil locality

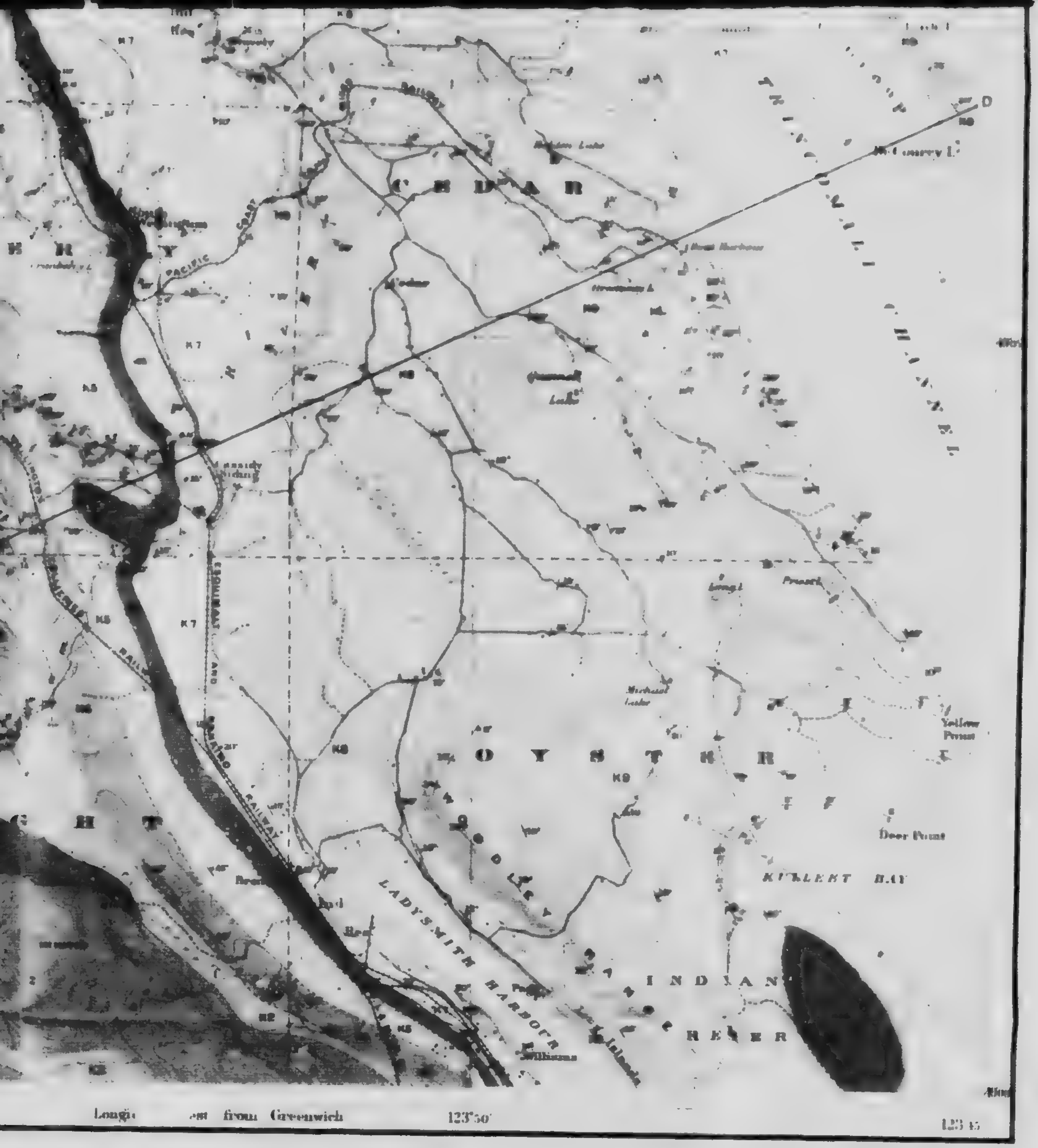


C.O. Senécal, *Geographer and Chief Draughtsman.*
C.G. Aitken *and* A.M^c Gregor, *Draughtsmen*



Scale, 100 Miles to 1 Inch

To accompany Memoir by C.H. Clapp



District boundary

Section lines

Triangulation stations

Bench marks

VIII

Section numbers

Water

Rivers and lakes

Watercourses with intermittent flow

Fresh marshes

Salt marshes

Tidal flats

Springs

Relief

Contours
showing land forms and elevations above sea level Interval 50 feet

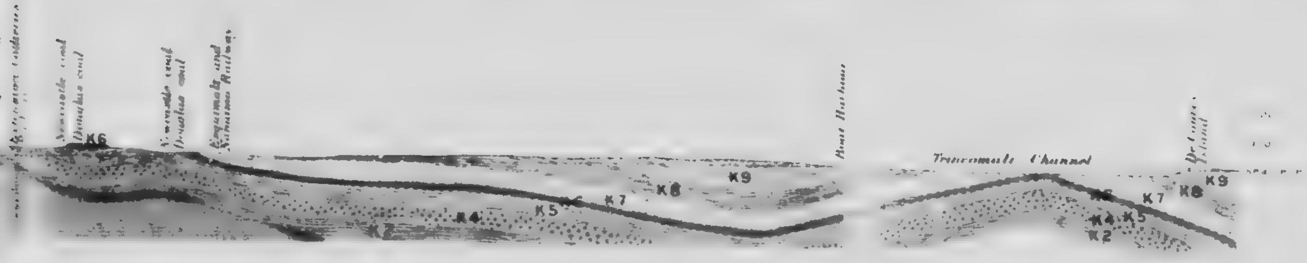
Depression contours

Sand

Figures showing heights in feet above sea level

Geographical position by triangulation based on U.S.C.& G.S. stations "Gonzales" and "Discovery", near Victoria

Average magnetic declination 25 East



Structural section along line C D
Scale, horizontal and vertical $\frac{1}{62,500}$

MAP 158 A
Issued 1916

NANAIMO SHEET
VANCOUVER ISLAND
BRITISH COLUMBIA

Scale $\frac{1}{62,500}$

Miles

Kilometres

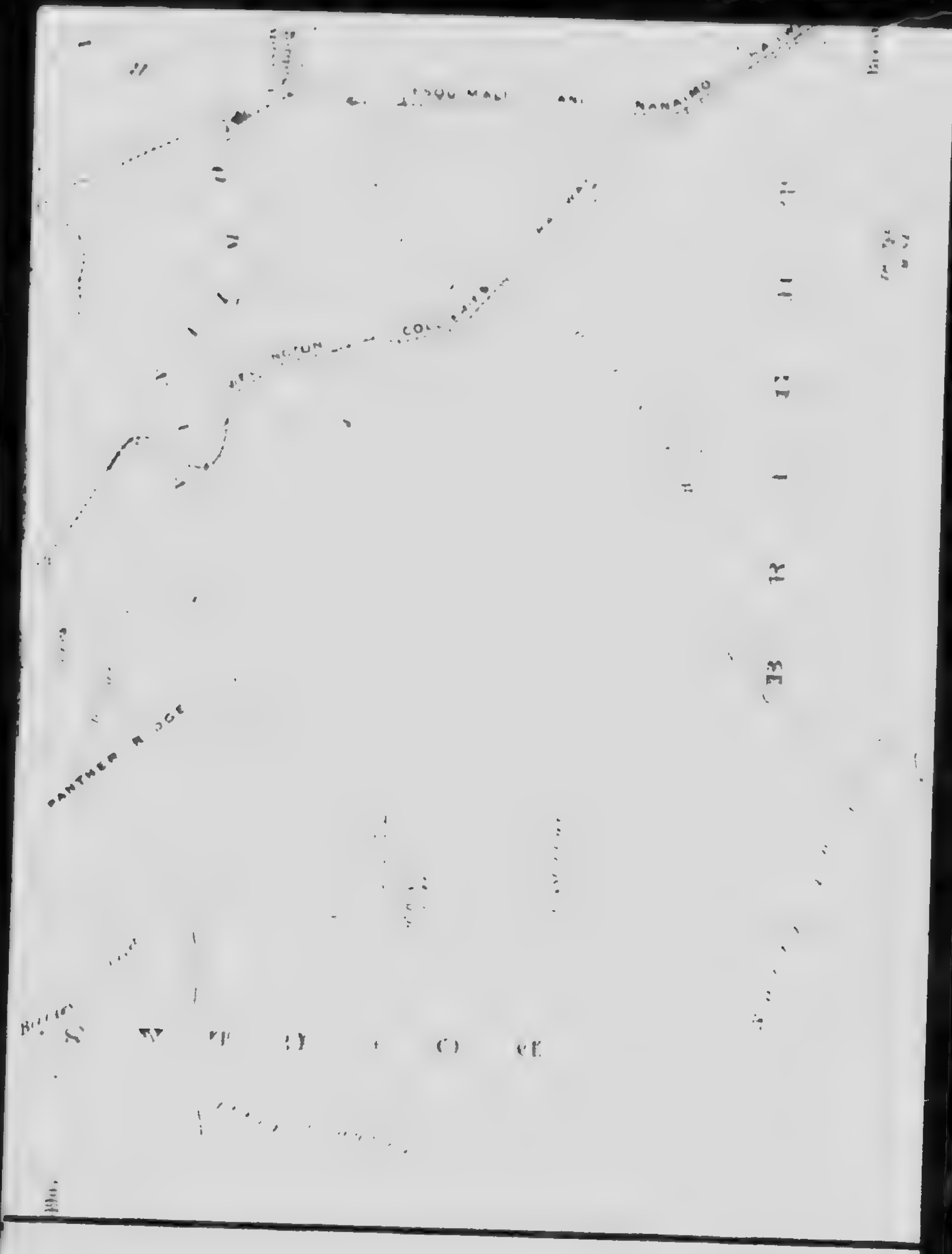
Note. For practical purposes assume
I MILE TO I INCH

GEOLOGY

C.H.CLAPP	191

TOPOGRAPHY

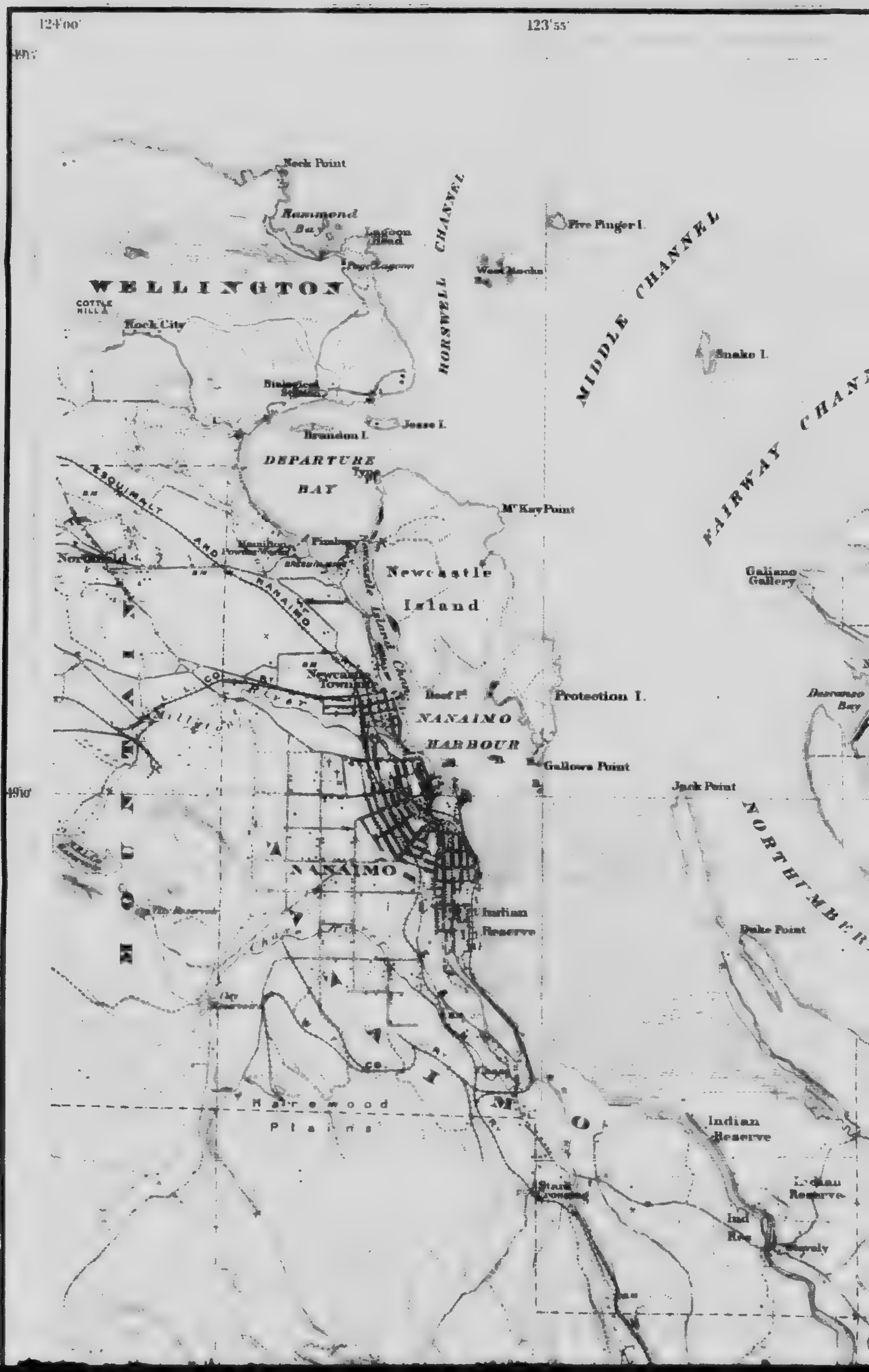
P.H.CHAPMAN IN CHARGE	1910
B.R.MACKAY	1910
[illegible]	1910
S.C. McLEAN TRIANGULATION	1909


NANAIMO
PANTHER RIDGE

Canada
Department of M

HON L. CODERRE, MINISTER, R.G McCONNEL

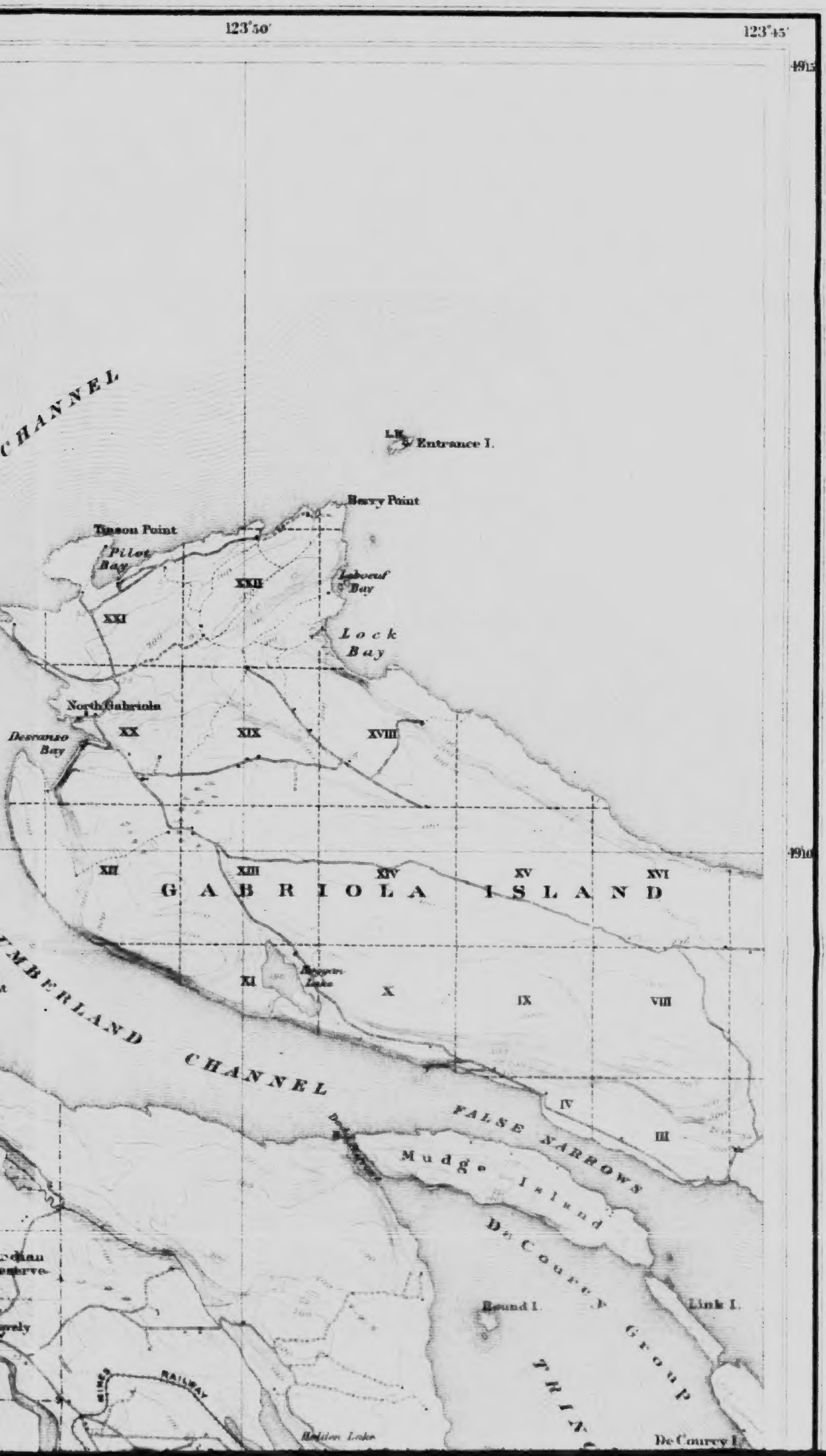
GEOLOGICAL SURVE



ada
t of Mines

Mc CONNELL, DEPUTY MINISTER

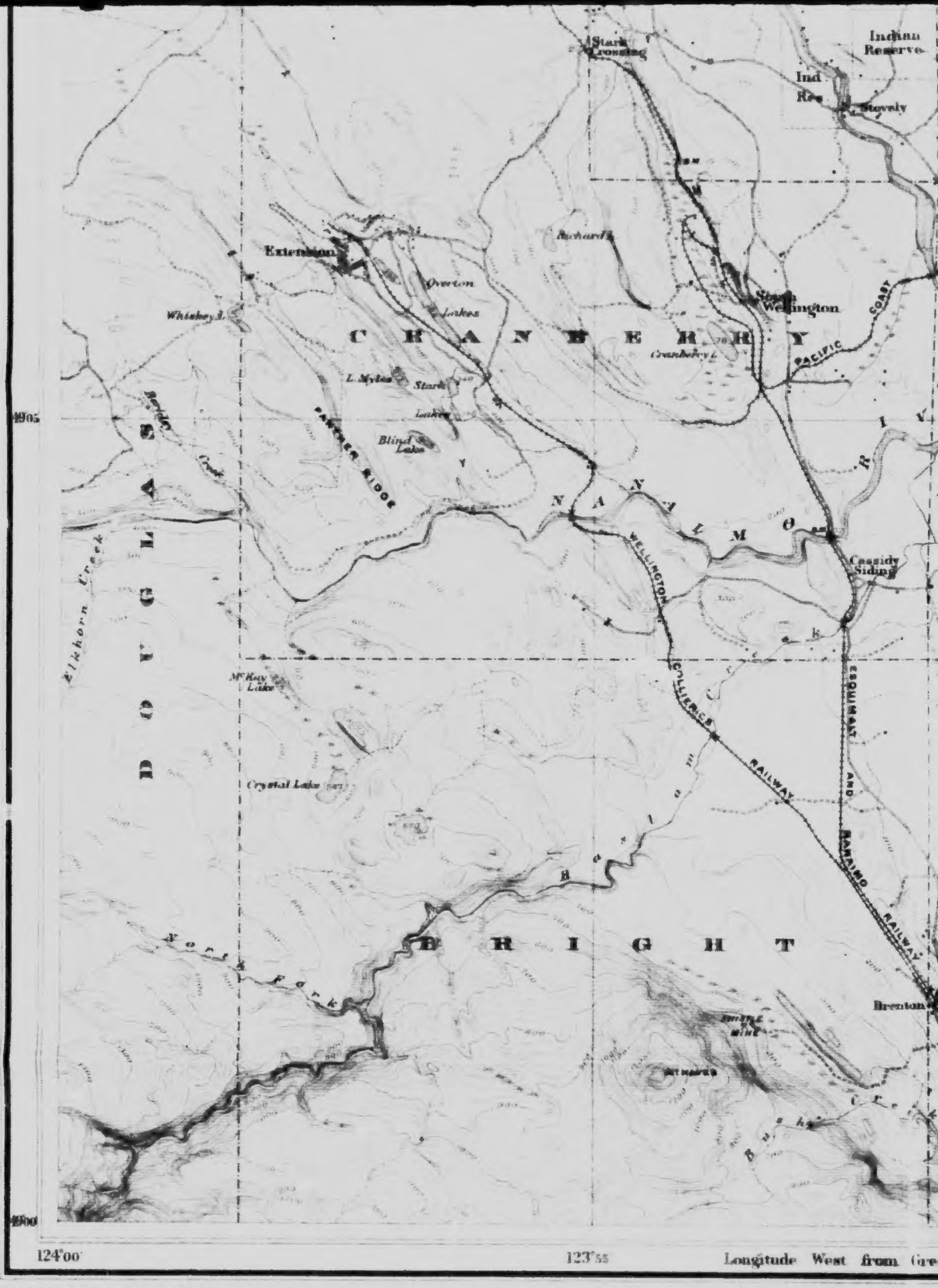
. SURVEY



LEGEND

Culture

- Streets, roads and buildings
- Private roads or roads not well defined
- Trails
- Railways
- Mine tramways
- Bridges
- Churches
- Schools
- Post Offices
- † † Cemeteries
- ⚒ Mines and quarries
- Shafts
- Y Tunnels
- × Prospects
- Dams
- Wharves
- L.H. Lighthouses
- B. Beacons
- District boundaries
- Section lines



C.O. Senécal, *Geographer and Chief Draughtsman.*
G.G. Aitken, *Draughtsman.*

MAP 33 A
(Issued 1915)

Scale. 100 Miles to 1 Inch

NANAIMO S

VANCOUVER ISL

BRITISH COLUMB

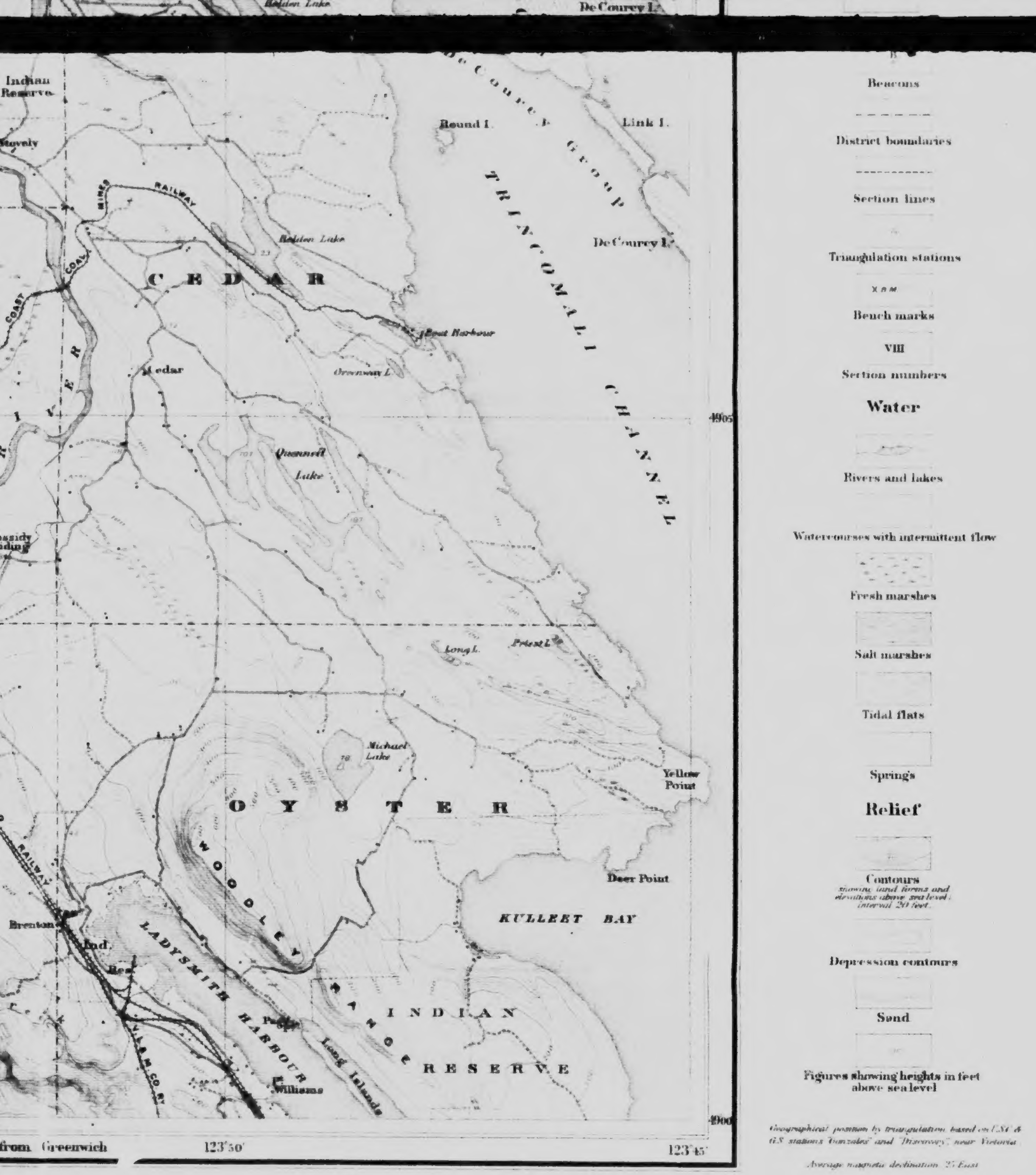
Scale $\frac{1}{62,500}$

Miles

Kilometres

Note. For practical purposes
I MILE TO I INCH

To accompany Memoir by C.H. Clapp



Geographical position by triangulation based on U.S.C. & G.S. stations "Gonzales" and "Discovery", near Victoria.

Average magnetic declination 25° East

33 A
1915

D SHEET
ER ISLAND
COLUMBIA

62,500
es
etres

purposes assume
D 1 INCH

TOPOGRAPHY

R.H. CHAPMAN, (IN CHARGE)	1910
B.R. MACKAY	1910
F.S. FALCONER	1910
S.C. McLEAN (TRIANGULATION)	1909